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A Study on Emergency Supply Chain and Risk Based on Urgent Relief Service in Disasters

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Abstract

In order to make the affected areas receive urgent relief service timely and accurately after the disasters, the effective operation of emergency logistics and quick response to the urgent demands in the affected areas is very critical. In this paper, firstly, the emergency supply chain management in disasters is presented, and the risk of disasters and urgent relief decision-making are analyzed, then the support mechanism of emergency logistics including infrastructure support, unified command and network coordination, law guarantee, contingency plan and emergency transportation channel is analyzed. Secondly, the evaluating indicators are specified by introducing the salvable degree concept, the salvable degrees of the affected areas which lie on the impact degrees of relief demands in the corresponding affected areas are analyzed and evaluated by the extension technique, and then a two-objective optimization model with the urgent relief demand time-varying fill rate maximization and the urgent relief distribution time-varying window minimization is developed in order to distribute urgent relief to the identified affected area sets. Finally, a numerical example demonstrates our conclusions.

Keywords: Emergency supply chain; Emergency logistics distribution; Salvable; Extension technique; Two-objective optimization

1. Introduction

In recent years, there are various kinds of serious disasters either natural occurring (e.g., earthquake, typhoons, floods, drought) or man-made (e.g., the 9.11 event in the USA) around the world, such as the tsunami in the Indian Ocean (2004), the Katrina Hurricane in the US (2005), as well as the Sichuan earthquake in China (2008) (Ergonul S., 2005; Chandre, Monerawela, Baskett., 2007). These disasters have caused severe damage to our world. For instance, in the Sichuan earthquake and its aftershocks in 2008 in China, 69,185 people died, 18,403 people went missing and a large number of houses were destroyed, and a large number of people were homeless unable to secure livelihoods (Lefei L, Shuming T., 2008). In order to support rescue operation after disasters, the urgent relief service must be delivered to the affected areas as quickly as possible, i.e., the quick-responsive emergency logistics system is needed for the relief service operations. For example, in the Sichuan earthquake, in the first day, 19 helicopters and 6 cargo-transport planes were assigned to the affected areas. Approximately 150 tons of relief resources including foods, waters, drugs, and so on were delivered to the affected areas. In a sense, emergency logistics became the lifeline in the affected areas associated with Sichuan earthquake. From a global point of view, over the last several years, changes in environment and society relationship have raised the requirement for effective emergency logistics to a new level, and emergency logistics issues lie in justifiable concerns and research interests.

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Different from general business logistics, emergency logistics is unique in the following four aspects that may increase the relative complexity and difficulty in solving the induced emergency logistics issues, particularly in terms of emergency logistics distribution problem, i.e., (1) *The urgent relief services are very diverse and urgent.* Generally, disasters often cause serious casualties and make many buildings severely damaged, so various kinds of urgent relief service goods such as waters, foods, medicines, shelters, medical equipments are needed to deliver to the affected areas in the immediate way, which maintain the daily needs of the corresponding survivals and alleviate the disaster impact. Furthermore, for emergency logistics, the timely availability of urgent relief service has a direct effect on the survival rate in the affected areas after the disasters. So the quick response to urgent relief services supplied for the affected areas is very critical. (2) *The accurate and real-time urgent relief demand information is almost inaccessible*. Unlike general business logistics in which the demand information (e.g., product orders) is provided actively and directly by end customers or the entire supply chain, the sources of on-the-spot relief demand information may be limited and almost unidentifiable in the immediate aftermath. In most disasters, such on-the-spot affection information may not be actively and timely provided by the affected people under the emergency conditions. (3) *The benefits of emergency logistics operation are always weakened.* Commonly, the general business logistics pursues the objectives of maximizing both efficiency and profits of logistics operation. However, for emergency logistics, the goal associated with the service benefits is often weakened. Sometimes, emergency logistics only focuses on the logistics service efficiency, regardless of the profits. For example, in order to distribute urgent relief to the affected areas quickly after disasters, the transportations (such as plane) with higher costs but higher speed are always needed, which will increase transport costs greatly. (4) *Government and the market participate in the emergency logistics service together*. The urgent relief service in emergency logistics is usually supplied by government, public organizations, firms, individuals and so on, which has decentralized storage. Under this circumstance, government who acts as a coordinator or organizer should take effective measures to integrate the urgent relief activities and resources, i.e., the government should efficiently collaborate with corporations and individuals to respond to the disasters.

While there are a variety of theoretical considerations for general business logistics from the presented literatures, there is still a lack of a theory for the emergency logistics, particularly with regard to the emergency logistics distribution. The main research works are expatiated as follows: The significance of issues on urgent relief service supply to the affected areas suffering from disasters, e.g., drought, earthquakes, typhoon etc., which can result in emergency logistics problems are addressed previously (Kembell C.D., Stephenson R., 1984; Ardekani S.A., Hobeika A., 1988; Long D.C., Wood D.F., 1995), Brown G.G. & Vassilion A.L.(1993) based on the diverse linear programming models presented for emergency logistics planning. However, a clear definition of emergency logistics has not yet been well clarified, unlike general business logistics which has been clearly defined in the previous literatures (Bowersox D.J., Closs D.J., 1996; Ballou R.H., 1999; Johnson J.C., Wood D.F., 1999). Usually, the emergency logistics is a process of planning, managing and controlling the efficient flows of urgent relief, information and services from the origin point to the destination points to meet the urgent needs of the affected areas under emergency conditions (Jiuh-Biing Sheu, 2007). In this paper, considering the urgent relief service, the emergency logistics is defined as: A process of planning, managing and controlling the efficient flows of urgent relief service, information and resources from the origin point to the destination points to meet the urgent service needs of the affected areas under emergency conditions. Obviously, considering the emergency logistics, quick and feasible response to the urgent relief services in affected areas after disasters is a critical objective. From the quantitive research, the presented literatures are reflected: Most formulate the corresponding urgent relief distribution problems as multi-commodity multi-modal flow problems with time windows (Rathi A.K. Church R.L., Solanki R.S., 1992; Haghani A, Oh S.C., 1996). Fiedrich *et al.* (2000) develop a dynamic combinatorial optimization model to find the optimal resource rescuing schedule with the objective of minimizing the total deaths during the search and rescue period. Barbarosoglu *et al*. (2002) propose a bi-level hierarchical decomposition approach for helicopter plan during a disaster relief service operation, where the top-level programming model is formulated to solve the tactical decision problems, involving the helicopter fleet management, crew assignment and the tour number undertaken by each helicopter. Özdamar *et al.* (2004) point out that the emergency logistics plan can be obtained by solving the dynamic time-dependent transportation problem, where the objective aims to minimize unsatisfied demands of all commodities throughout the planning horizon. The emergency logistics plan includes the optimal pick-up and delivery schedules for vehicles within the considered planning time horizon as well as optimal quantities and types of loads picked up and delivered on these routes. Wei *et al.* (2007) propose an ant-colony optimization based on the heuristic technique to solve the multi-commodity and vehicle dispatching problems that appear in disaster relief activities. The distinctive feature the method is that the original emergency distribution problem is decomposed into two phases decision making, i.e., the vehicle routes construction and the multi-commodity dispatch, where vehicles, urgent relief service and wounded people are regarded as commodities. Tzeng *et al.* (2007) formulate the urgent relief distribution model by using a fuzzy multi-objective programming, in which the fuzzy weights associated with the objective functions are introduced, thus the considerable flexibility adaptive decision support system based on urgent relief distribution is presented.

However, disasters occur abruptly with a large-area strong destructive force generally, which makes the urgent relief services could not be fully satisfied in time. So it is necessary to evaluate the affected areas to determine respective emergency distribution priority. Some literatures reflected this issue, e.g., by evaluating the severity degrees associated with the affected areas. The greater severity degree indicates relatively the urgent demand of relief is scheduled to receive the relief service with the higher priority (Jiuh-Biing Sheu, 2007). Essentially, this approach puts emphasis on the past damage induced by disaster. However, the objective of urgent relief distribution is to alleviate the disaster impact by rescuing the trapped survivals and saving the damaged private property, the important fundamental facilities (e.g., electrical equipment and communication equipment), the valued assets of the bank (e.g., bank treasury and customer information) and so on, i.e., the salvable trapped people and damaged state and private property should be attached importance to evaluate the affected areas. Probably, the first contributors in evaluating the salvable degrees of the affected areas are An C and Tiantian L. (2007, 2008). The salvable evaluation is defined as the remediation measurement of the current and future possible disaster losses during the disaster, and then a quantitative evaluation model is presented. Based on the above mentioned, the salvable concept will be introduced in this paper, and the affected areas are classified according to the evaluated salvable degrees, which could provide decision support for the urgent relief distribution. In order to evaluate the salvable degrees of the affected areas in disasters, the extension approach will be used in this paper. The extension approach often deals with multi-variable problems and can help analysis of a problem in combination with quality and quantity. With this framework, one can extend some model sets and key strategic sets to help decision makers make assistance decisions (Guojun J, 2006). In addition, the urgent relief service operation involves the coordination operation of an entire supply chain collaboration, but it is worth noting the supply chain itself faces the disruption risk in the affected areas after the disasters. Supply chain risk management (SCRM) is aimed at developing approaches to identify, analyze, evaluate and treat the vulnerability and risk appeared in SCs (Neiger *et al.*, 2009). Nowadays, many facts reflect risks, such as the increasing outsourcing, globalization, reducing supplier. In addition, micro-operation results in risks, includes reducing inventory or zero inventory, increasing demand, JIT distribution or short product life cycles (Norrman and Jansson, 2004) are presented the importance to SCRM. These are several practical examples that respond to various risk events resulting in high costs (Chopra and Sodhi, 2004).

The structure of this paper is organized as follows: In Section 2, supply chain management in disasters is analyzed and the risk of disasters and urgent relief service decision-making are discussed. In section 3, the support mechanism of emergency logistics is analyzed, a mathematical formulation model of the emergency logistics distribution is developed, and a case study based on earthquake is presented to demonstrate our conclusions. Finally, conclusions are reflected in Section 4.

2. Supply Chain Management in Disasters

2.1 The Challenges of the emergency SCM system in disasters

Firstly, though at present there are many emergency SCM systems being sold in the computer markets, it's hard for governments to find a suitable one that can be used in disasters. One can see that all those software manufacturers are claiming that their emergency SCM system software can help governments to improve their efficiency. This phenomenon can only be called a mixed blessing. On one hand, it is good for governments because governments will have more chances to select more competitive emergency SCM system software. On the other hand, it also increases the difficulties of selection. We know that some disasters often break out so suddenly, so time will be too urgent for a suitable software to be found in such a complex market. Secondly, it's hard to learn well a new emergency SCM system in so short a time. Although the standard supply chain software can technically be very mature and very easy to learn, but the problem we are facing is that we hardly have any time in the great disasters. Thirdly, the situations in different disasters with different magnitude scale in different location will be quite different. So there will be different requirements for software designing. Furthermore, some governments have already formed their own emergency SCM system partly and may not want to build a new system according to the standard software. Some of them prefer to choose to build more special emergency SCM system software. Then it will require those governments to list out rapidly their working processes, organization structures, the benefits and challenges and shortcomings of their existing part etc. So it will be a very complex and difficult work to satisfy those modifying requirements in such a short time.

Effective operation of the emergency SCM system is affected by many factors, which greatly increases the difficulties of emergency SCM system operation. For example, a great number of money should be invested to pay the related employees; much time and energy should be invested for the maintenance of supply chain system; lots of information from the service receivers, such as people in the earthquake -stricken areas should be dealt with timely and effectively. What's worse, earthquakes often occur randomly and all in a sudden, so it will be quite difficult to well arrange so many factors for the emergency SCM system in such a short time. Therefore, it is wrong to believe that only one supply chain software can solve all the problems in the operation process of emergency SCM system.

2.2 The solutions of the emergency SCM system

One characteristic of the disasters is that they usually break out all in a sudden. So we cannot count on all the things well when the disaster has already happened. Earlier preparation and precaution will be very important for dealing with some urgent disasters including earthquakes. In their normal days, governments should think about establishing a self-contained, smoothly-worked emergency SCM system in case there will be some sudden disasters. With the emergency SCM system being built, when disaster attacks, people in the disaster-stricken areas can directly report their requirements to their local governments through the emergency SCM system, and then the higher level governments can give orders to the local governments directly also by the system. It will greatly decrease the time, energy and money waste. What's more, a well-worked emergency SCM system can also help with their daily management. Different governments and aid enterprises have different inner and exterior surroundings. Due to the uncertainties in the disaster, it requires both of them to invest enough resources including labors, R&D, computers, suitable software and so on. Most of the software packages for creating the emergency SCM are quite expensive and require advanced ITs, advanced database systems, local and wide-area communications linkages, which also require a large amount of investment (Wagner, 2001). And, financial support is also crucial in maintaining the security and stability of emergency SCM system. Therefore, if governments/aid resources providers need and want to build an emergency SCM integration system, they must increase the deposit of labor, R&D personnels, computers, suitable software, especially money. They also need to increase their plan deposit.

To build a more smooth information flow structure within governments and aid enterprises, SCMs structures of Chinese governments are composed of four different levels, with the Chinese central government being the highest level ,the province governments the second, the city governments the next, and the county and the town governments the lowest. So, it totally has 3-6 joints in Chinese governments SC system, which is too many and is easy to make the demand or supply information distorted. Therefore, it is necessary for governments of all levels to strength the communication in their daily work, especially in the earthquakes. This will help to decrease the information distortion and the negative effects of bull whip effects. Independent enterprises are different benefit parts but they have the common aims to meet their customers' demands (Narus and Anderson, 1996). The supply chain members have the same benefits and they would like to work for each other. Also they prefer to share some useful information to optimize the emergency SCM system. Collaboration can improve the profit and decrease their cost. The upstream enterprises and down enterprises can run effectively just like one unity of the one organization. A collaborative supply chain is able to achieve the whole emergency SCM system agilely.

In an emergency SCM system, it is essential to strengthen the collaborative SC. From all levels of governments to a solely and small aid material organization, no one of them is one isolated body. Instead, they are a close unity. Emergency collaborative supply chain in the emergency SCM system for governments includes three types, namely message-based system that transmits information to neighbor governments, applications using technologies such as XML messages; electronic procurement hubs in which collaborative planning, forecasting and replenishment (CPFR) can share the isolated information. (Mclaren, Head & Yuan, 2002).

2.3 The Risk of Urgent Relief Service Decision-making

In urgent relief service decision-making, the improvisation decision-making is an effective approach (Wachtendorf, 2004), the improvisation decision-making refers to in a certain time limitation and emergency situations, without ready-made plan, decision-makers can act according to circumstances, past experience and present knowledge, by using all kinds of methods, timely adjusting deployment of urgent relief service, establishing a plan to meet the diverse service demand to achieve the purpose of quickly defusing the crisis, i.e., the urgent relief improvisation decision-making is an reengineering technique of experience and knowledge, is an innovation process of timely planning based on the urgent relief environmental demands. The urgent relief improvisation decision-making has some risks, compared to the conventional decision-making, mainly there are the following features: (1) The urgent relief improvisation decision-making to the timeliness requirements are more stringent. Different from the conventional decision support is that urgent relief improvisation decision-making is time-bound. The available time for urgent relief service is less, the available resources are limited, and the available plans are fewer. As time goes by, the urgent relief scopes gradually expand, the search space may be getting smaller and smaller, which will make the urgent relief service response more tardive. So, it is required within a certain time to quickly generate a feasible preference. To avoid losses of people or property etc., the decision-maker constitutes a feasible plan only before the serious consequences, the disasters' negative impact on the social, psychological, environmental and other aspects can reach a minimum, thereby this urgent relief improvisation decision-making is effective, meaningful and successful. (2) The urgent relief improvisation decision-making is a kind of fuzzy decision-making technique. In the conventional decision-making, the initial goals are usually clear. However, in the urgent relief improvisation decision-making, due to sudden, unconventional, disorder and other characteristics emergency, the presented environmental characteristics, patterns are not complete, the decision objective is often vague and non-quantitative, and time is changing. The main objective of urgent relief service is to minimize the loss of people, property and environment damage caused by disaster and to maximize to protect the survivals and properties, so this is the multi-objective decision-making problem. Usually, the historical disposal strategy cannot be copied or replicated in the presented plan. In many cases, the urgent relief improvisation decision-making depends on the decision makers' on-the-spot knowledge, game experience, subjective judgments and other personal preferences. The urgent relief improvisation decision-making program may not require the best option, but it is the available program in a certain time, available options are not perfect correct, and the results of programs or measures are less risky. (3) The urgent relief improvisation decision-making is a dynamic decision-making process. There are some literatures presented the decision-making is always to complete a dynamic cycle process of observe, orient, decide, act, and this process is called "OODA Loop". The urgent relief improvisation decision-making also needs the loop decision-making process. Since the emergency shows the rapid variability and uncertainty, decision-makers must in accordance with the current dynamic events adjust the disposal strategy as quickly as possible. (4) The urgent relief improvisation decision-making is a group decision-making technique. The urgent relief service includes transportation supplier, medicare sector, communications organization, fire protection and other sectors etc. Usually the decision-making is not just an individual behavior, it needs joint exchange ideas of multi-participants and information to work together to identify a satisfactory and viable option. Theses participants may come from different fields or organizations, or concentrate in one place, or need an interactive platform of network communications or more extensive information.

The urgent relief improvisation decision-making plan must have the greatest reliability, but because of the complexity and uncertainty of urgent relief service, the very accurate decision-making is also difficult to reach. In short, based on the urgent relief service features, the decision-maker should in-depth think the disaster complexities to thoroughly develop a variety of action plans. In order to complete the detailed plan, the decision-maker must be based on a flexible decision to respond to the scene situation changes, so that the conventional decision-making and improvisation decision-making are complementary effectively to achieve the purpose of urgent relief service.

3. The Support Mechanism of Emergency Logistics and Distribution Model

3.1 The support mechanism of emergency logistics

In the emergency logistics system, there is large amount of relief services. To ensure the affected areas after the disaster could receive relief service timely and accurately, it is important to make relief service to have the sufficient, the smooth, the correct way etc. To ensure the logistics process is easy to control and the logistics operation is fast, some support tools to satisfy the prerequisite of the emergency logistics effective operation are required. This mainly reflects in: (1) *Infrastructure Support*. The infrastructure support is critical for the operation of emergency logistics, which includes transportation network, storage infrastructure and information exchange platform etc. The well designed transportation network and storage infrastructure could distribute the relief service to the affected areas quickly. Information network connected with the governmental public information platform would share the accurate information involving the dynamic development conditions of the disaster, the transportation and storage state timely, and provide decision-making support. In a word, an emergency logistic system must have fast response and wide coverage function so that it can improve the operational efficiency greatly. (2) *Unified Command and Network Coordination*. The emergency logistics operation usually reflects the social functions, so it needs participation of the whole society. Generally, the government firstly should set up an unified command agency and establish a integrated network after the disaster so as to coordinate various kinds of capacities, formulate the reasonable relief distribution plans and organize the dispatch commands; secondly, the government is amenable to collect the rescue funds through every possible ways, including fundraising, donation acceptance etc., and mobilizes the firms to produce the relief goods, thereby upgrade the relief service quick response capability; thirdly, the government should take right measures to reduce or eliminate the impact of processing disaster obstacles. (3) *Law Guarantee*. Law guarantee in the emergency logistics operation is not only an active mobilization mechanism, but also a compulsive support mechanism. Firstly, laws related to the relief service could help to recognize different rights and obligations of the general and injured publics after the disaster. Secondly, the laws can keep the social stability in the affected areas. For different disasters, many countries have enacted the corresponding laws, for example, “The National Emergency State Law” of America, “Flood Fighting Law” and “Earthquake Defending and Disaster Alleviating Law” of China etc. (4) *Contingency Plan*. Because disasters have the characteristics of outburst, time and space uncertainty, and difficult to account the risk degrees etc., the efficient emergency logistics contingency plan is essential, the plan may be comprised in “hardware” and “software” contents. The hardware includes the relief service models, the relief reserve funds, infrastructures and goods etc. The software involves the expert teams (e.g., doctor), volunteers, exchange information, contingency measures etc. (5) *Emergency Transportation Channel*. After the disasters, constructing a feasible emergency transportation channel in the affected areas as well as striving for many countries supports is very important to optimize the relief service process and increase the relief service speed, thereby help to distribute the relief and rescue workers quickly, and improve the emergency logistics operational efficiency so as to reduce the loss caused by the disasters.

3.2 The distribution models of emergency logistics

The problem is how to efficiently distribute the urgent relief service from the multiple urgent relief distribution centers to various affected areas in the crucial rescue period after a disaster. Here, the urgent relief distribution center is defined as the relief hub. Generally, considering the specific logistics requirements and capacity quantities, such a distribution center should be dominated by the public sector, e.g., the local government or the corresponding regional rescue organizations.

To be convenient for model formulation, five assumptions are given as follows: (1) After a disaster, the rescuers are supposed to alleviate the disaster impact of survivals and private property, i.e., the main objects of the relief service operation can be divided into increasing survivals and reducing damaged property. Consequently, the salvable evaluation in the affected areas could be based on the aspects of the survivals and the damaged property. However, considering the survivals are more important than that of property after the disaster, in this paper, the salvable degrees mainly are based on the survivals, regardless of the damaged property. (2) The quantities of affected areas and the corresponding geographic relationships in the time window are known. Considering that such data can be accessible in real time via the advanced disaster detection technology, e.g., the satellite remote sensor. (3) The updated information about the damaged conditions, and casualties within each affected areas can be obtained during the rescue period. (4) The relief service time-varying and the relief supply time-varying in each urgent relief distribution center can be estimated based on historical data or expert knowledge. (5) For each kind of relief service, each given distribution center’s relief amount doesn’t exceed its aggregate transportation capacity, which includes the loading capacity of vehicles in each time window. Based on the above assumptions, firstly, we present the salvable evaluating indicators in a given time window by using extension technique, and then rank them according to the salvable degrees. Secondly, a two-objective optimization model with the objectives of the relief demand time-varying fill rate maximization and the relief distribution time-varying time minimization is developed in order to distribute relief service to the identified affected areas.

The matter-element concept of extenics gives us a new answer to solve synthetically evaluating problems based on the salvable indicators in the emergency logistics distribution, since the method combines with qualitative and quantitative analysis, so some variables problems could be described as the relative matter-element matrix. The current demand data can be obtained from the historical record, which will provide the urgent relief service sectors such as the emergency logistics distribution center to rapidly respond to a variety of relief services according to the salvable degrees. The output refers to the identified affected area sets in the current period, which will be as the input of the following period to further help the emergency distribution decision.

Now, three evaluating indicators are specified as follows: (1) c_1 represents the ratio of observed dead relative to the total population in a given affected area within a given time window. In general, a higher dead ratio may indicate lower salvable degree in the corresponding affected area. (2) c_2 denotes the building damaged conditions, such as the damaged buildings are serious or complete destruction in a given affected area within a given time window. Generally, the building damaged conditions may reflect the the disaster how effect on the survival probabilities in certain extent. Accordingly, the more higher building damaged degree may indicate the more lower salvable degree. (3) c_3 denotes the distance state, which includes the traffic condition, environmental state, geographic location associated with a given affected area in a given time interval. For instance, after an earthquake, whether the affected area is located in the epicentre has great impact to the salvable degree. Usually, the longer distance away from the epicenter may indicate a higher salvable degree.

Therefore, we have 3 quantitative and qualitative indicators associated with each given affected area, i.e., c_1, c_2, c_3. With the expert evaluation technique or fuzzy statistical method, we can classify the salvable degree into I standard ranks, and a synthetical evaluating matter-element model is presented as follow:

$$R_{0i} = \begin{bmatrix} P_{0i} & c_1 & V_{0i1} \\ & c_2 & V_{0i2} \\ & c_3 & V_{0i3} \end{bmatrix} = \begin{bmatrix} P_{0i} & c_1 & \langle a_{0i1}, b_{0i1} \rangle \\ & c_2 & \langle a_{0i2}, b_{0i2} \rangle \\ & c_3 & \langle a_{0i3}, b_{0i3} \rangle \end{bmatrix}, (i = 1,2,\cdots,I)$$

(1)

Where R_{0i} denotes the salvable matter-element in the affected areas salvable matter-element lies in i rank, P_{0i} denotes the i rank affected area, and $V_{0ij} = \langle a_{0ij}, b_{0ij} \rangle, (j = 1,2,3)$ denotes the size of evaluating indicator c_j under i rank. The allowable scale matter-element model based on all synthetical evaluating indicators follows:

$$R_0 = \begin{bmatrix} P_0 & c_1 & V_{01} \\ & c_2 & V_{02} \\ & c_3 & V_{03} \end{bmatrix} = \begin{bmatrix} P_{0i} & c_1 & \langle a_{01}, b_{01} \rangle \\ & c_2 & \langle a_{02}, b_{02} \rangle \\ & c_3 & \langle a_{03}, b_{03} \rangle \end{bmatrix}, (i = 1,2,\cdots,I)$$

(2)

Where R_0 denotes the section field, P_0 denotes the whole affected area set, $V_{0j} =< a_{0j}, b_{0j} >, (j = 1,2,3)$ denotes the allowable size of indicator c_j under P_0, and $V_{0ij} \subset V_{0j}, (i = 1,2,\cdots,I; j = 1,2,3)$. For the waiting evaluating affected area, the sample data can be used in following matter-element model:

$$R = \begin{bmatrix} P & c_1 & v_1 \\ & c_2 & v_2 \\ & c_3 & v_3 \end{bmatrix}$$

(3)

Where P indicates the waiting evaluating affected area, and $v_j (j = 1,2,3)$ denotes the evaluative value of j indicator.

In practical, the accessible degree can be determined by different techniques. Here, we consider correlation function approach as follows:

$$\rho(v_j, V_{0ij}) = \left| v_j - \frac{a_{0ij} + b_{0ij}}{2} \right| - \frac{b_{0ij} - a_{0ij}}{2}, (i = 1,2,\cdots,I; j = 1,2,3)$$

(4)

$$\rho(v_j, V_{0j}) = \left| v_j - \frac{a_{0j} + b_{0j}}{2} \right| - \frac{b_{0j} - a_{0j}}{2}, (j = 1,2,3)$$

(5)

(4) and (5) denotes the accessible degrees (or distance correlative degrees) between point v_j and sets V_{0ij}, V_{0j}, respectively. For instance, if $\rho(v_j, V_{0j}) > 0$, that means $v_j \notin V_{0j}$; if $\rho(v_j, V_{0j}) \leq 0$, that means $v_j \in V_{0j}$, and different values denote that v_j locates in different V_{0j}. Let

$D(v_j, V_{0j}, V_{0ij}) = \rho(v_j, V_{0j}) - \rho(v_j, V_{0ij}), (i = 1,2,\cdots, I; j = 1,2,3)$ denotes the distance state value between v_j and V_{0j}, V_{0ij}.

Defining that

$$C_i(v_j) = \frac{\rho(v_j, V_{0ij})}{D(v_j, V_{0j}, V_{0ij})}, (i = 1,2,\cdots, I; j = 1,2,3)$$

(6)

(6) reflects the correlative degree has evaluating indicator C_j based on the i rank affected area matter-element. If $C_i(v_j) \geq 0$, that means $v_j \in V_{0ij}$, and more bigger $C_i(v_j)$ reflects v_j having more characteristics of V_{0ij}; if $C_i(v_j) \leq 0$, that means $v_j \notin V_{0ij}$, and more smaller $C_i(v_j)$ reflects v_j far from V_{0ij}.

Assume that $\alpha_j (j = 1,2,3)$ ($\sum_{j=1}^{3} \alpha_j = 1$) is the weighted coefficient of the *j* evaluating indicator, which is often determined by the subjective estimation. Sometimes, based on the historical data or the problem structures, AHP or Delphi techniques can be used in determining these coefficients. Then the synthetical correlative degree between the waiting affected areas and i rank affected areas follows:

$$C_i(P) = \sum_{j=1}^{3} \alpha_j C_i(v_j), (i = 1,2,\cdots, I)$$

(7)

Let $r(P) = \{i_0 \mid C_{i_0}(P) = \max_{1 \leq i \leq I} C_i(P)\}$, this means that the waiting evaluating affected area *P* belongs to i_0 rank salvage.

Based on the above mentioned, we can evaluate the salvable degrees of the given affected areas in given time window to rank these affected areas.

Suppose that there are M_t affected areas at *t*. Through the aforementioned procedure, we can rank these affected areas in order $r_m(t), (m = 1,2,\cdots, M_t)$. Herein, we introduce the parameter λ_t, which denotes pre-determined distribution threshold involving the available logistics resources and the expert knowledge. If $r_m(t) \geq \lambda_t, (m = 1,2,\cdots, M_t)$, then the affected area *m* will receive the relief service at *t*, or else it will be excluded. In succession, the set of the affected areas are planned to be distributed relief service that is planned to distribute to the affected areas at *t* is expressed as A_t, where the same rank affected areas will supply the same relief distribution service. The i affected areas set rank at t is represented as $B_i(t), (i = 1,2,\cdots, I)$, which meets $\bigcup_{i=\lambda_t} B_i(t) = A_t$.

3.3 Rank-based Relief Distribution

Next, a two-objective optimization model is formulated to reflect the urgent relief service's distribution problem, which the distribution is from urgent relief distribution centers to various affected areas at *t*.

Suppose that there are N_t urgent relief distribution centers at *t*. Let $D_m^l(t)$ denote the relief service associated with relief l of the affected area m at t, and $X_{nm}^l(t)$ is a decision variable that denote the quantities of relief l distributed from the urgent relief distribution center n to a given affected area m at t. For each affected-area set $B_i, (i = \lambda_t, \lambda_t + 1, \cdots, I)$, the relief service fill rate at *t* could be represented as follows:

$$H_{B_i}(t) = \frac{\sum_{l \in L} \sum_{n=1}^{N_t} \sum_{m \in B_i} X_{nm}^l(t)}{\sum_{l \in L} \sum_{m \in B_i} D_m^l(t)}, (i = \lambda_t, \lambda_t + 1, \cdots, I)$$

(8)

Since the affected area sets are planned to different relief distribution service priorities, we introduce weighted coefficient $\beta_i(t)$ reflects the impact of each affected area set $B_i(t)$ that meets $\sum_{i=\lambda_t}^{I} \beta_i(t) = 1$ and $\beta_i(t) \geq 0, (i = \lambda_t, \lambda_t + 1 \cdots, I)$. Accordingly, the objective function with the relief service time-varying fill rate maximization within the affected-area set A_t could yield as follows:

$$\max \sum_{B_i} H_{B_i}(t) \times \beta_i(t)$$

(9)

To rescue the survivals in the affected areas and alleviate the disaster impact efficiently, the affected areas must receive corresponding relief service as fast as possible, i.e., the time window of relief distribution has a great effect on the relief distribution efficiency. Let $T_{nm}^l(t)$ denote the shortest time window related with relief l from urgent relief distribution center n to the affected area m at t, which could be calculated by Shortest Path Method, e.g., Dijkstra Algorithm (Liang D., 2003). Therewith, the objective function associated with the relief distribution time-varying window minimization could be expressed as follows:

$$\min \quad \sum_{l\in L}\sum_{n=1}^{N_t}\sum_{m\in A_t} X^{l}_{nm}(t)T^{l}_{nm}(t)$$

(10)

Accordingly, the two-objective optimization model could be formulated as follows:

$$\max \quad \sum_{B_i} H_{B_i}(t)\times\beta_i(t)$$

(11)

$$\min \quad \sum_{l\in L}\sum_{n=1}^{N_t}\sum_{m\in A_t} X^{l}_{nm}(t)T^{l}_{nm}(t)$$

(12)

$$s.t.\quad \begin{cases} \sum_{n=1}^{N_t} X^{l}_{nm}(t)\le D^{l}_{m}(t) & \forall m\in A_t, l\in L \\ \sum_{m\in A_t} X^{l}_{nm}(t)\le S^{l}_{n}(t) & \forall n\in\{1,2,\cdots,N_t\}, l\in L \\ X^{l}_{nm}(t)\ge 0 & \forall m\in A_t, n\in\{1,2,\cdots,N_t\}, l\in L \end{cases}$$

(13)

Where L is the set of relief l, and $S^{l}_{n}(t)(n\in N_t, l\in L)$ denotes the relief service supplies relief l by the urgent relief distribution center n at t.

Here, the first constraint condition may ensure that the aggregate amount of relief l distributed to the affected area m at t, which should not exceed the corresponding relief service $D^{l}_{m}(t)$.The second constraint indicates the relief amount distributed from urgent relief distribution center n should not exceed the corresponding available relief amount at t. Furthermore, the third constraint condition characterizes a feasible field associated with each decision variable $X^{l}_{nm}(t)$.

Considering the relief service fill rate is more important than the relief distribution time window generally, the Lexicographic Method can be used to solve the two-objective optimization model, which involves two major computational steps summarized as follows (Ou W, Lv E.L., 2005):

Step 1: Solve the following optimization model involving a single objective function associated with the relief service fill rate.

$$\min \quad -\sum_{B_i} H_{B_i}(t)\times\beta_i(t)$$

$$s.t.\quad \begin{cases} \sum_{n=1}^{N_t} X^{l}_{nm}(t)\le D^{l}_{m}(t) & \forall m\in A_t, l\in L \\ \sum_{m\in A_t} X^{l}_{nm}(t)\le S^{l}_{n}(t) & \forall n\in\{1,2,\cdots,N_t\}, l\in L \\ X^{l}_{nm}(t)\ge 0 & \forall m\in A_t, n\in\{1,2,\cdots,N_t\}, l\in L \end{cases}$$

(14)

Then, the optimal solutions of the model is described as $X^{l}_{nm1}(t),(\forall m\in A_t, n\in\{1,2,\cdots,N_t\}, l\in L)$.

Moreover, the objective function minimization value could be calculated as $-\sum_{B_i}\frac{\sum_{l\in L}\sum_{n=1}^{N_t}\sum_{m\in B_i} X^{l}_{nm1}(t)}{\sum_{l\in L}\sum_{m\in B_i} D^{l}_{m}(t)}\times\beta_i(t)$.

Step 2: Substituting the above values into corresponding constraint inequality, the second optimization model involving a single objective function associated with the relief distribution time window is formulated as follows:

$$\min \quad \sum_{l\in L}\sum_{n=1}^{N_t}\sum_{m\in A_t} X^{l}_{nm}(t)T^{l}_{nm}(t)$$

(15)

$$s.t.\begin{cases}\sum_{n=1}^{N_t} X_{nm}^{l}(t) \le D_m^l(t) & \forall m \in A_t, l \in L\\ \sum_{m\in A_t} X_{nm}^{l}(t) \le S_n^l(t) & \forall n \in \{1,2,\cdots,N_t\}, l \in L\\ X_{nm}^{l}(t) \ge 0 & \forall m \in A_t, n \in \{1,2,\cdots,N_t\}, l \in L\\ -\sum_{B_i}\frac{\sum_{l\in L}\sum_{n=1}^{N_t}\sum_{m\in B_i} X_{nm}^{l}(t)}{\sum_{l\in L}\sum_{m\in B_i} D_m^l(t)}\times\beta_i(t) \le -\sum_{B_i}\frac{\sum_{l\in L}\sum_{n=1}^{N_t}\sum_{m\in B_i} X_{nm1}^{l}(t)}{\sum_{l\in L}\sum_{m\in B_i} D_m^l(t)}\times\beta_i(t)+a \end{cases}$$

(16)

Where $a(a>0)$ is the slack variable of the objective function associated with the relief service fill rate. Generally, the parameter a is determined by the decision makers preference associated with the value of $-\sum_{B_i}\frac{\sum_{l\in L}\sum_{n=1}^{N_t}\sum_{m\in B_i} X_{nm1}^{l}(t)}{\sum_{l\in L}\sum_{m\in B_i} D_m^l(t)}\times\beta_i(t)$.

The satisfactory solutions associated with the model optimal solutions are described as $X_{nm2}^{l}(t)(\forall m \in A_t, n \in \{1,2,\cdots,N_t\}, l \in L)$.

3.4 The numerical example

The next numerical example is to demonstrate the above method. Here, we consider a destructive earthquake happened in 15 areas (called as area-1 to area-15 in order) and 3 urgent relief distribution centers (called as center-1, center-2 and center-3) at t_1. By using the expert evaluation technique, the affected areas salvable degree is classified with 5 ranks (namely, $I=5$), and the evaluating matter-element models are given as follows:

$$R_{01}=\begin{bmatrix} P_{01} & c_1 & <0.5,1> \\ & c_2 & <2,3> \\ & c_3 & <0,3> \end{bmatrix},\quad R_{02}=\begin{bmatrix} P_{02} & c_1 & <0.3,0.5> \\ & c_2 & <2,3> \\ & c_3 & <3,5> \end{bmatrix},\quad R_{03}=\begin{bmatrix} P_{03} & c_1 & <0.15,0.3> \\ & c_2 & <2,3> \\ & c_3 & <5,7> \end{bmatrix},$$

$$R_{04}=\begin{bmatrix} P_{04} & c_1 & <0.05,0.15> \\ & c_2 & <1,2> \\ & c_3 & <7,8> \end{bmatrix},R_{05}=\begin{bmatrix} P_{05} & c_1 & <0,0.05> \\ & c_2 & <1,2> \\ & c_3 & <8,10> \end{bmatrix}.$$

Where, c_2 is quantified by the expert judgement, which is specified from rank 1 to rank 3, where rank 1 denotes medium; rank 2 denotes significance; rank 3 denotes very significance, and c_3 is determined by the distance away from the epicenter.

Then, the synthetical matter-element model could be expressed as follows: $R_0=\begin{bmatrix} P_0 & c_1 & <0,1> \\ & c_2 & <1,3> \\ & c_3 & <0,10> \end{bmatrix}$

To the 15 affected areas, the corresponding statistical values at t_1 are summarized in Table 1.

Table 1. Statistical values of the dead ratio, the distance away from the epicenter at t_1

The affected areas	C_1 : The ratio of the number of dead casualty	C_2 : building damage conditi ons	C_3 :The distance away from t he epicenter/10 Km
area-1	0.01	1	10
area-2	0.02	1	9
area-3	0.05	2	7.5
area-4	0.06	2	7.2
area-5	0.08	2	8
area-6	0.09	2	6
area-7	0.1	2	5
area-8	0.1	3	4
area-9	0.12	3	6
area-10	0.13	3	7
area-11	0.15	2	2
area-12	0.2	3	3
area-13	0.2	3	2.5
area-14	0.25	3	1.5
area-15	0.3	3	0

Here, the distribution threshold are determined by $\lambda_{t_1}=3$, and the weight values are chosen by

$\alpha_1 = \frac{2}{5}, \alpha_2 = \frac{1}{5}, \alpha_3 = \frac{2}{5}$. Thereby, based on the known data, we can calculate the salvable degrees of the 15 affected areas, and then get the sets of affected areas that would be distributed relief service in the time window, i.e., $B_3(t_1) = \{\text{area-9}, \text{area-12}\}$, $B_4(t_1) = \{\text{area-3}, \text{area-4}, \text{area-5}, \text{area-6}, \text{area-7}, \text{area-8}, \text{area-10}\}$, $B_5(t_1) = \{\text{area-1}, \text{area-2}\}$,
$A_t = \{\text{area-1}, \text{area-2}, \text{area-3}, \text{area-4}, \text{area-5}, \text{area-6}, \text{area-7}, \text{area-8}, \text{area-9}, \text{area-10}, \text{area-12}\}$.

In addition, the corresponding parameters $D_m^l(t_1), S_n^1(t_1), T_{nm}^l(t_1)$ are shown in Table 2, Table 3 and Table 4, and the weight coefficients values are determined by $\beta_3(t_1) = \frac{1}{6}, \beta_4(t_1) = \frac{1}{3}, \beta_5(t_1) = \frac{1}{2}$.

Table 2. Statistical values of the relief demand associated with relief $l, (l = 1,2,3,4)$ of the affected area $m(m \in A_{t1})$ at t_1

m : The affected areas	$D_m^1(t_1)$	$D_m^2(t_1)$	$D_m^3(t_1)$	$D_m^4(t_1)$
area-1	10,000	3,000	200	300
area-2	12,000	5,000	600	500
area-3	10,000	4,000	400	300
area-4	15,000	8,000	900	700
area-5	13,000	6,000	700	600
area-6	20,000	10,000	1,000	900
area-7	18,000	9000	9,00	900
area-8	25,000	12,000	1,300	1,200
area-9	30,000	15,000	1,700	1,500
area-10	30,000	15,000	1,600	1,400
area-12	40,000	20,000	2,100	2,000

Where, $l = 1$: water (gallon), $l = 2$: food (ton), $l = 3$: medicine (ton), and $l = 4$: shelter (set).

Table 3. Statistical values of relief supply associated with relief $l(l = 1,2,3,4)$ at the urgent relief distribution center $n(n = 1,2,3)$ at t_1

n : The urgent relief distributio n center	$S_n^1(t_1)$	$S_n^2(t_1)$	$S_n^3(t_1)$	$S_n^4(t_1)$
center-1	30,000	15,000	2,500	1,000
center-2	70,000	35,000	3,000	3,500
center-3	80,000	30,000	3,000	2,500

Table 4. Statistical values of the shortest time window related with relief $l(l = 1,2,3,4)$ from urgent relief distribution center $n(n = 1,2,3)$ to the affected area $m(m \in A_{t1})$ at t_1

$T_{nm}^l(t_1)$/hour	center-1	center-2	center-3
area-1	5	7	9
area-2	6	9	8
area-3	8	15	18
area-4	8	12	20
area-5	12	18	10
area-6	20	7	12

area-7	25	9	15
area-8	10	15	10
area-9	18	20	15
area-10	15	10	10
area-12	28	15	20

Where $T_{nm}^{l}(t_1)$ is uncorrelated with l, i.e., $T_{nm}^{l}(t_1) = T_{nm}^{2}(t_1) = T_{nm}^{3}(t_1) = T_{nm}^{4}(t_1)$, $(m \in A_{t1},\ n = 1,2,3)$.

Accordingly, the satisfactory solutions $X_{nm2}^{l}(t_1)(\forall m \in A_{t_1}, n \in \{1,2,3\}, l \in \{1,2,3,4\})$ could be calculated by using the LINDO package, the results are shown in Table 5 to Table 8. Our optimal results show that goods are assigned to the different areas suitably.

Table 5. The optimal results based on $X_{nm2}^{1}(t_1)$ ($l = 1$: water)

n	area-1	area-2	area-3	area-4	area-5	area-6	area-7	area-8	area-9	area-10	area-12
1	5000	0	10000	15000	0	0	0	0	0	0	0
2	5000	0	0	0	0	20000	18000	0	27000	0	0
3	0	12000	0	0	13000	0	0	25000	0	30000	0

Table 6. The optimal results based on $X_{nm2}^{2}(t_1)$ ($l = 2$: food)

n	area-1	area-2	area-3	area-4	area-5	area-6	area-7	area-8	area-9	area-10	area-12
1	0	197	4000	8000	0	0	0	2803	0	0	0
2	3000	4803	0	0	0	10000	9000	0	8197	0	0
3	0	0	0	0	6000	0	0	9197	0	14803	0

Table 7. The optimal results based on $X_{nm2}^{3}(t_1)$ ($l = 3$: medicine)

n	area-1	area-2	area-3	area-4	area-5	area-6	area-7	area-8	area-9	area-10	area-12
1	0	600	400	900	0	0	0	600	0	0	0
2	200	0	0	0	0	1000	900	0	900	0	0
3	0	0	0	0	700	0	0	700	0	1600	0

Table 8. The optimal results based on $X_{nm2}^{4}(t_1)$ ($l = 4$: shelter)

n	area-1	area-2	area-3	area-4	area-5	area-6	area-7	area-8	area-9	area-10	area-12
1	0	0	300	700	0	0	0	0	0	0	0
2	300	500	0	0	0	900	900	0	900	0	0
3	0	0	0	0	600	0	0	1200	0	700	0

Where the slack variable is given by $\alpha = 0.2$.

4. Conclusions

To make the affected areas receive relief service timely and accurately after the disasters, the mechanisms to ensure the emergency logistics effective operation and quick response to the urgent relief service demands in affected areas are very critical. In this paper, firstly, the emergency supply chain management in disasters is presented, and the risk of disasters and urgent relief decision-making are analyzed, then the support mechanism of emergency logistics including infrastructure support, unified command and network coordination, law guarantee, contingency plan and emergency transportation channel is analyzed. Secondly, the evaluating indicators were specified by introducing the salvable degree, the salvable degrees of the affected areas which determine the relief services degrees were evaluated by the extension technique, and then a two-objective optimization model with the time-varying fill rate maximization of relief service in the affected areas and the relief distribution time-varying time window minimization was developed in order to distribute relief service to the identified affected area sets. Finally, a numerical example demonstrated our conclusions. There are some open problems, such as how to coordinate the emergency logistics network, for example, how multi-member coordinates the network; since the variables have not been fully considered, for example, the law guarantee mechanism does not reflect in the models.

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