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Theories and Methods for the Emergency Rescue System

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1. Introduction

According to the "China State Plan for Rapid Response to Public Emergencies" (hereinafter referred to as "Plan"), which was published by the Central Government of the People's Republic of China, "public emergencies" refer to those emergencies that happened suddenly, and would (or might) cause heavy casualties and property loss, damage ecological environment, bring severe harms to our society and threat public safety. In the "Plan", public emergencies were divided into four categories: natural disasters, accidental disasters, public emergencies and social security events.

Since long time ago, the progress of human society has been achieved at the cost of deteriorating our living environment. Consequently, the number of natural or manmade disasters has been increasing. Earthquakes, floods, hurricanes, nuclear leakages, sudden outbreak of infectious diseases, fires and explosions attacked the human-beings one after another. For example, the Great Hanshin Earthquake in Japan in 1995, the "September 21" Earthquake in Taiwan in 1998, the "September 11" Terrorist Attack in US in 2001, the "August 14" Power Failure in US and Canada in 2003, and the disastrous Indian Ocean Tsunami in 2005, have brought severe losses to local economy, peoples' life and property.

As we all know, public emergencies, particularly natural disasters, are unavoidable. But we could reduce the loss of disasters to a minimum, or even eliminate the negative impact of disasters, by designing an appropriate emergency rescue system. For example, in 2005, the southern United States was attacked by Hurricane Katrina. The local government failed to allocate emergency resources in a timely manner. Consequently, the local people didn't have enough emergency supplies, such as food, drinking water, the necessities of life and medicine. Due to the severe shortage of emergency supplies, many disaster-stricken people resorted to violence. Riots occurred in many places, making the situation even worse.

Another example is the 7.6-magnitude earthquake happened on South Asian Subcontinent in October 2005. The disaster-stricken areas were faced with several problems: 1) Water supply was interrupted. The local residents didn't have food to eat. 2) Hospitals were shut down. The residents were in urgent need of medical care. 3) The traffic conditions were poor in disaster-stricken areas. The disaster-stricken people didn't have enough emergency resources to make their living. Consequently, they ransacked shops for food and medicine and severely undermined the local social order.

These two examples have fully revealed the importance of designing a sophisticated emergency rescue system. The loss of public emergencies would be greatly reduced by understanding the distribution of disaster-stricken people and providing appropriate emergency resources to them. Otherwise, the public emergencies would be uncontrollable. To make things worse, the situation of disasters might be more serious, and even lead to the breakout of secondary disasters.

2. Problem statement

When we design an emergency rescue system, we need to coordinate the manpower with the financial, material resources. It is a complicated process to optimally allocate various elements within a system. It involves a wide range of contents. Repeated researches should be made on several theories and methods. Designing of an emergency rescue system covers the following four aspects (See Figure 1):

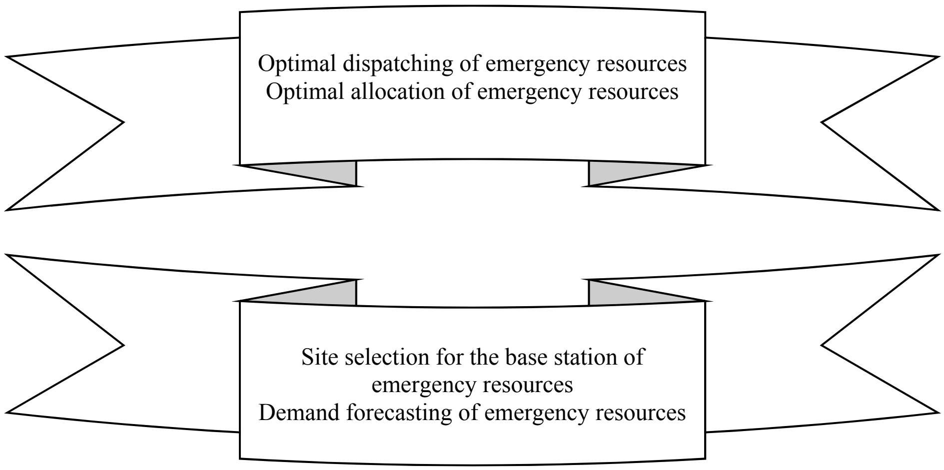

Fig. 1. Research Course for the Emergency Rescue System.

These four aspects have been cross-linked each other essentially.

1. Demand Forecasting of Emergency Resources

In recent years, unconventional emergencies frequently broke out, severely endangered people's life and property. How to timely predict people's demand on resources after the disasters? This issue has become an important problem for us.

Here, a precise predictive method has been designed by combining the Fuzzy Set Theory with the Learning Rules of Hebb Neural Network, Multiple Linear Regression and Case

Reasoning. By applying this method, we have solved the problems of information insufficiency and inaccuracy when we predict the resource demand after unconventional emergencies, and could correctly predict people's demand on resources.

2. Optimal Site Selection for the Base Station of Emergency Resources

If the resource demand has been determined, sufficient emergency resources need to be transported to the emergency base stations (Emergency rescue station). To achieve this goal, how many base stations for emergency resources should be established, and where should we establish these stations, these issues will be worth considering. In other words, we should optimally select the sites of base stations and find appropriate locations within a certain region as the base stations of emergency resources. The number of location should also be suitable. When disasters break out, we could allocate resources from these base stations to deal with the emergencies. By optimally selecting the sites of base stations, we could not only reduce costs, but could also ensure the timeliness of emergency resources, making these resources arrive at the emergency scenes quickly, safely and timely.

Here, a summarization has been made on relevant site selection knowledge, and the Operations Research theories have been applied based on the existing site selection methods. A multistage model of site selection has been designed to make an optimal planning on the number and location of base stations. Example analysis has also been made to verify the results of calculation. It has been proved that this model is simple, convenient for use, and could get results quickly. This model would be suitable for the site selection and planning of base stations of emergency resources.

3. Appropriate Allocation of Emergency Resources

The emergency resources deployment is a hardcore of emergency management. After the happening of the public emergency, it is important to study how to deliver the emergency resources to base stations quickly. When we've determined the location of base stations, we should optimally allocate emergency resources. More to this point, it should predetermine the number, type and quality of resources for each base station. Otherwise, there's an important constraint condition for us to consider: the costs.

This chapter proposed the dynamic optimal process of emergency resources deployment planning, making use of Markov decision processes, and discovered the optimal deployment planning to guarantee the timelines.

4. Optimal Dispatching of Emergency Resources

Aiming at solving the resource allocation problems in case of emergency events, this chapter presented an optimum mathematical simulation model based on the dynamic programming.

In accordance with the number of emergency base stations, the given model tries to divide the resource allocation procedure into the some stages. The stated variable stands for the amount of the emergency resource available for allocation can be used at the beginning of each stage. As is depicted in the dynamic programming theory, the remaining resource of the previous stage may have a strong influence on the succeeding stage. During each stage, three factors may restrict the object function, that is, the remaining resource, the decision, and the demand. The total function is the sum of the object function of each stage. In addition, the concrete case can be used to confirm the model's validity and practicability. The results of our repetitive experimental application of the model show that it works perfectly for its duty in improving the efficiency of emergency management and overcoming the problem of wasting emergency resource as well as low efficiency in emergency rescue.

3. Methods

3.1 Emergency resources demand prediction using case-based reasoning

3.1.1 Research background

Public emergencies usually bring great negative impacts on economy and society, cause damage on casualties and property, bring destructions on ecological environment and human living environments, have adverse impacts on social order and public safety, and even arise social and political instability. Moreover, due to the change and influence of multiple factors, the type, occurrence probability and influence degree of public emergencies are increasing.

The demand on emergency resources refers to the minimum guarantee requirements for effective response to public emergencies. The so-called effective response refers to that the response on public emergencies should be efficient, and it also refers to that the emergency resources should be used with high efficiency. While the minimum guarantee requirements refer to that the smallest demands are needed when public emergencies are successfully solved. Obviously, an optimized idea is involved in the determination of emergency resource demand, meaning that under some given parameters such as type, intensity and influencing range of Emergency response, the smallest resource demand required for the successful response to public emergencies.

Currently, there are few researches on this aspect, in most cases the emergency decision maker subjectively decides whether the quantity, quality and type of emergency resources are rational and can meet the requirements of emergency. Besides, due to the particularity of emergency process, the effect of cost is smaller than that of time effect, so that in many cases, no efforts are spared to conduct the emergency rescue. But the method is easily to cause the irrational demand of emergency resources, so that it is unscientific and will cause groundless waste of numerous resources, meaning that a scientific prediction method is sorely needed to achieve the prediction on the demand of emergency resources.

Case-based reasoning (CBR) is a relatively new problem solving technique that is attracting increasing attention. For a long time, expert systems or knowledge-based systems (KBS) are one of the success choices in Artificial Intelligence (AI) research. The *first generation* KBS, and today's systems, are based upon an explicit model of the knowledge required to solve a problem. When it comes to so called *second generation* systems, a deep causal model was adopted to enable a system to reason using first principles [1]. But whether the knowledge is shallow or deep an explicit model of the domain must still be elicited and implemented often in the form of rules or perhaps more recently as object models. However, knowledge elicitation is a difficult process, often being referred to as the knowledge elicitation bottleneck; implementing KBS is a difficult and slow process requiring special skills; and once implemented they are difficult to maintain [2-6].

Over the last few years an alternative reasoning paradigm and computational problem solving method has increasingly attracted more and more attention. Case-based reasoning (CBR) solves new problems by adapting previously successful solutions to similar problems. CBR is attracting attention because it seems to directly address the problems outlined above. CBR does not require an explicit domain model and so elicitation becomes a task of gathering case histories, implementation is reduced to identifying significant features that describe a case, an easier task than creating an explicit model, by applying database techniques largely volumes of information can be managed, and CBR systems can learn by acquiring new knowledge as cases thus making maintenance easier.

The work Schank and Abelson in 1977 is widely held to be the origins of CBR [7]. They proposed that our general knowledge about situations is recorded as scripts that allow us to set up expectations and perform inferences. Whilst the philosophical roots of CBR could perhaps be claimed by many what is not in doubt is that it was the work of Roger Schank's group at Yale University in the early eighties that produced both a cognitive model for CBR and the first CBR applications based upon this model [8]. Janet Kolodner developed the first CBR system called CYRUS [9-11]. An alternative approach came from Bruce Porter's work, at The University of Texas in Austin, into heuristic classification and machine learning resulting in the PROTOS system [12-13].

In the U.S., Edwina Rissland's group at the University of Massachusetts in Amherst developed HYPO [14]. This system was later combined with rule-based reasoning to produce CABARET [15].

In Europe, the first one is that of Derek Sleeman's group from Aberdeen in Scotland. They studied the uses of cases for knowledge acquisition, developing the REFINER system [16]. Mike Keane, from Trinity College Dublin, undertook cognitive science research into analogical reasoning [17]. Michael Richter and Klaus Althoff in the University of Kaiserslautern applied CBR to complex diagnosis [18]. This has given rise to the PATDEX system [19] and subsequently to the CBR tool S3-Case. In the University of Trondheim, Agnar Aamodt has investigated the learning facet of CBR and the combination of cases and general domain knowledge resulting in CREEK [20-21].

In the UK, CBR seemed to be particularly applied to civil engineering. A group at the University of Salford was applying CBR techniques to fault diagnosis, repair and refurbishment of buildings [22]. Yang & Robertson [23] in Edinburgh developed a CBR system for interpreting building regulations, a domain reliant upon the concept of precedence. Another group in Wales applied CBR to the design of motorway bridges [24].

Further, there are active CBR groups in Israel [25-26], India [27] and Japan [28].

3.1.2 Methods for emergency resource demand prediction

According to the characteristics of emergency resource demand prediction process, both the risk analysis and case-based reasoning method are introduced into the process, accordingly a case-based reasoning method for emergency resource demand prediction based on risk analysis is obtained, which improves the scientificity of emergency resource demand. The case-based reasoning flow for emergency resource demand prediction based on risk analysis is shown in Fig.2.

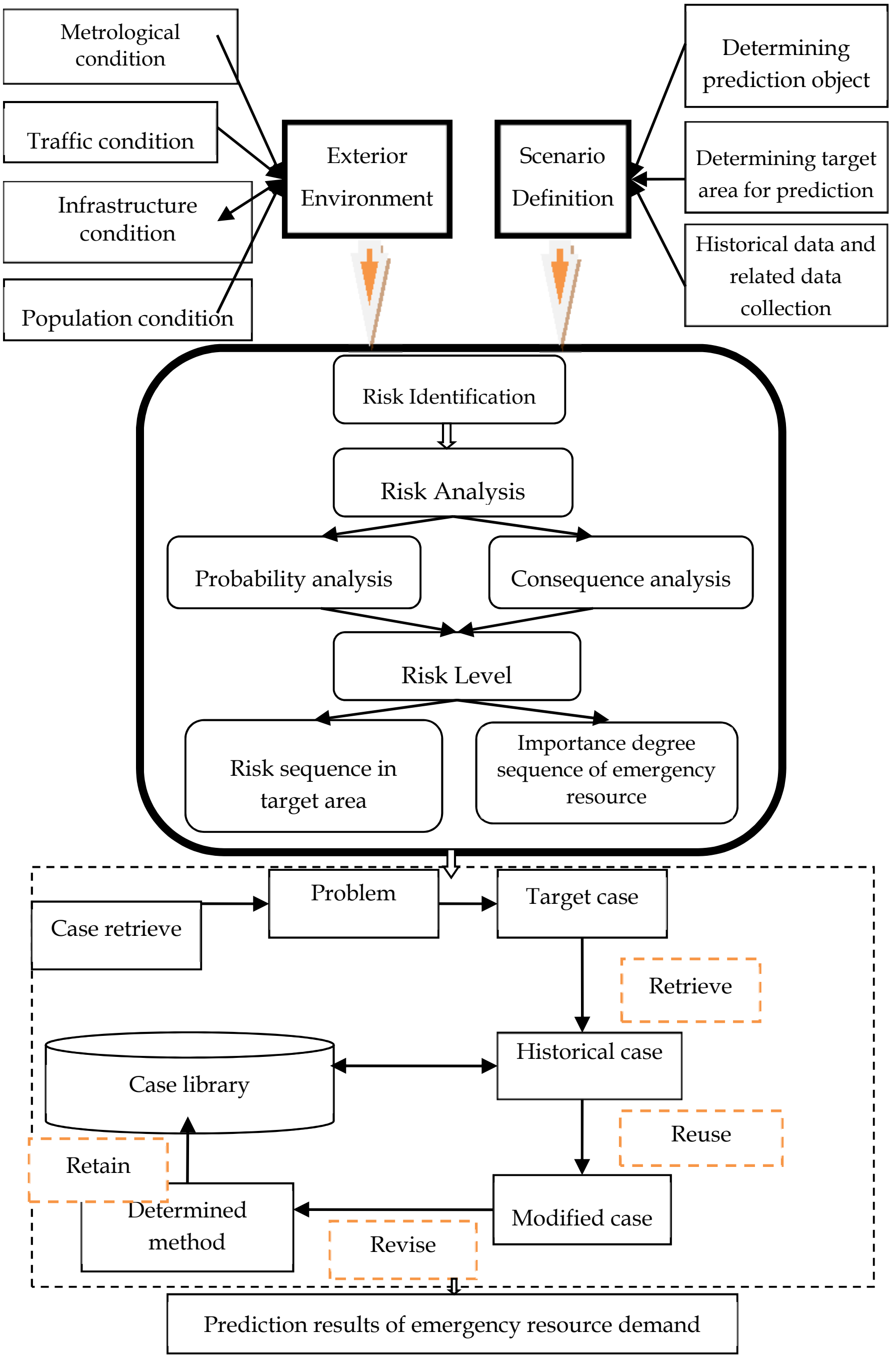

Fig. 2. Case-based reasoning prediction on emergency resource demand based on risk analysis.

The case-based reasoning is a comprehensive form of three types of human thoughts including imaginal thinking, logical thinking and creative thinking. From the view of reasoning method, the case-based reasoning is an analogy reasoning from one case (old case) to another case (new problem), while from the view of knowledge, the case-based reasoning is a method based on memory in which old experiences are used to guide the problems. The CBR is generally composed of four main processes, including retrieve, reuse, revise and retain [29-30], so that CBR is also called 4R.

Therefore, in this paper, the case-based reasoning prediction method associated with risk analysis process is used to conduct demand prediction on the quantity, quality and type of emergency resources. After conducting risk analysis on target area, characteristic values of risk in these are can be obtained, including possible incident type, incident results, occurrence probability of incident, etc., accordingly the case-based reasoning process can be used for emergency resource demand prediction.

1. Expression of case

The case generally includes two parts, including case attribute description and case solution, of which the former one is the index structure of case and the latter one is the answer of case. While the emergency resource demand prediction is composed of three parts, including characteristic description of Emergency response, characteristic description of emergency rescue plan and description of emergency resource demand, all of which can be determined based on the results of risk analysis, namely risk probability and risk results.

- Characteristic description of Emergency response: it includes some characteristic information of Emergency response, including type, intensity, natural environment surround the occurrence site, population density, losses, duration time of hazard, etc., all of which depict and describe the characteristic attributes of Emergency response.
- Characteristic description of emergency rescue plan: it includes the characteristic attributes of emergency object, emergency rescue method, emergency procedure, etc. If there is a difference in the emergency object, way, technique and process of Emergency response of the same type, the material demands will be different too.
- Description of emergency resource demand: it includes the quantity, quality and type of emergency resources.

On the whole, in order to obtain complete data, the case should be described in detail as can as possible under the specific condition. Generally, one case can be composed of several attributes, all of which can be further divided, while the whole case library is composed of associated cases at different attribute levels. Therefore, in the emergency resource demand prediction, the case can be modeled as follows:

$$case\ (F, P, D)$$

In the formula: $F=(f_1, f_2,\ldots, f_n)$, f_n is a characteristic attribute of Emergency response, which can be obtained according to the results of risk analysis; $P=(p_1, p_2, \ldots, p_n)$, p_n is a characteristic attribute of emergency rescue plan; D is the demand attribute of emergency resource.

2. Case-based reasoning process of emergency resource demand

a. Characterization of emergency resource demand case

Given that there are n cases in the case library, the case i is expressed as C_i (i=1,2,…,n). Its characteristic factor set $B=\{b_1, b_2,\ldots,b_m\}$. Therefore, the membership function of case C_i to the characteristic factor b_j (j=1,2,…,m) is expressed as $n_{C_i}(b_j)$, and the characteristic vector corresponding to the case C_i in the case library is as follows:

$$V_{C_i} = \{n_{C_i}(b_1), n_{C_i}(b_2), \ldots, n_{C_i}(b_m)\} = \{n_{C_i}(b_j) \mid j = 1, 2, \ldots, m\} \qquad (1)$$

Given that the characteristic vector set of prediction plan is T, which can be expressed as the formula below:

$$V_T = \{n_T(b_1), n_T(b_2), \ldots, n_T(b_m)\} = \{n_T(b_j) \mid j = 1, 2, \ldots, m\} \qquad (2)$$

b. Emergency resource demand case retrieve-similarity calculation

According to the organization form of case, the nearest neighbour method is used. The nearest neighbour method is a method in which the cumulative sum of characteristic weights of the input case that is matched with the existing case in the case library is used to retrieve the case, namely that:

$$\frac{\sum_{i=1}^{n} w_i sim(b_i^I, b_i^R)}{\sum_{i=1}^{n} w_i} \qquad (3)$$

In the formula above: w is the important weight value of characteristic factor, *sim* is the similarity function, b^I and b^R is the input case value and retrieve case value of characteristic factor i.

In the similarity matching of cases using the characteristics of case, the effect of each characteristic is different, so that in the similarity calculation, it is necessary to assign different weights to each characteristic factor.

Given that the influencing weight set of the characteristic factor set $B=\{b_1, b_2,\ldots,b_m\}$ is $\{w_1, w_2,\ldots,w_m\}$, and the following condition is satisfied:

$$\sum_{j=1}^{m} w_j = 1, \quad j = 1, 2, \ldots, m \qquad (4)$$

Consequently, the similarity can be calculated by the formula below:

$$sim(A,B) = \frac{\sum_{j=1}^{m} w_j (n_A(x_j) \wedge n_B(x_j))}{\sum_{j=1}^{m} w_j (n_A(x_j) \vee n_B(x_j))} \qquad (5)$$

In the formula (5), $\wedge$ is the maximum lower limit, and $\vee$ is the minimum upper limit.

c. Weight calculation of characteristic factor

Generally, under different decision-making environments, the same characteristic factor has different effects on the decision output. Given that $n(b)$ represents the value of case when the characteristic factor is b. If there is a large difference in distribution of $n(b)$ in the case library C (C ={c_1, c_2,…,c_n}), which indicates that the factor has great effect on classification identification, and it should be assigned a larger weight value. On the contrary, if there is a small difference in distribution of $n(b)$ in the case library C (C ={c_1, c_2,…,c_n}), which indicates that the factor has little effect on classification identification, and it should be assigned a smaller weight value.

Therefore, each case in the case library can be classified into one type. Given the case C_i takes the value of $n(b_j)$ when the characteristic factor is b_j, the membership function of the case to the characteristic factor b_j can be expressed as $n_{C_i}(b_j)$, and the formula below can be obtained:

$$\overline{n}(b_j) = \frac{1}{n}\sum_{j=1}^{n} n_{C_i}(b_j) \tag{6}$$

Thus, the mean square deviation is expressed as the formula below:

$$\delta(b_j) = \left[\frac{\sum_{i=1}^{n}(n_{C_i}(b_j) - \overline{n}(b_j))^2}{n}\right]^{\frac{1}{2}} \tag{7}$$

The weight w_j of each characteristic factor can be obtained by the formula below:

$$w_j = \frac{\delta(b_j)}{\sum_{j=1}^{m}\delta(b_j)}, \quad j = 1,2,\ldots, \quad m \tag{8}$$

After the weight of characteristic factor is obtained, the similarity function is combined with the weight of characteristic factor, and the formula below can be obtained:

$$sim(T,C_i) = \frac{\sum_{j=1}^{m} w_j(n_T(x_j) \wedge n_{C_i}(x_j))}{\sum_{j=1}^{m} w_j(n_T(x_j) \vee n_{C_i}(x_j))} \geq \eta, \quad i = 1,2,\ldots,n \tag{9}$$

In the formula above, the similarity between target case T and C_i can be expressed as $sim(T,C_i)$ (∈[0,1]), η is a threshold value, and the learning strategies of case are divided into following types:

a. $\forall$ sim (T, C_i) =0, i∈[0, 1], the new case doesn't match with all cases in the case library, and it can be added into the case library;
b. $\exists$ sim (T, C_i) =1, i∈[0, 1], the new case is completely similar to certain case, and it can not added into the case library;
c. $\forall$ sim (T, C_i) <η, i∈[0, 1], the new case can be added into the case library;
d. $\forall$ sim (T, C_i) >η, i∈[0, 1], the solution for the case with maximum similarity (max[sim (T, C_i)]) is converted into the solution for new case.

All cases in accordance with the similarity calculation formula are the similar cases, among which the one with the maximum sim (T, C_i) is the most similar case. Accordingly, the material demands of the most similar case are taken as the prediction results of material demand when the Emergency response occurs.

3.2 Application of multi-stage location planning model in optimizing location of emergency resource base stations

3.2.1 Research background

Urban Planning refers to the specific method or process of predicting urban development and managing various resources to adapt to its development, to guide the design and development of built environments. While modern urban planning is trying to study the impact which a variety of economic, social and environmental factors have on the change of land using patterns, and develop planning reflecting the continuous interaction. Currently, in the process of making urban planning, parties have paid more and more attention to urban safety planning, in which the optimization of location planning of emergency logistics base station is one of the very important contents[31-33].

Emergency Logistics refers to the special logistics activities through which the necessary emergency supplies are provided to minimize the loss caused by unforeseen accidents and disasters in the shortest time, while an important role of emergency logistics base station (also known as emergency resource base station) is to provide adequate and timely emergency response resources to potential unforeseen accident or disaster sites[34-37].

The optimization of location planning of emergency resource base station includes determining reasonable position and scale of emergency resource base station, and since the special construction of emergency logistics base station costs a lot due to its specialization, so the optimization of the location planning of emergency resource base station should mainly start with two aspects, one is to determine the appropriate scale or the reasonable amount of emergency resource base stations, the other is to solve the problem of spatial distribution, namely, location optimization[38-40].

City T, as largest coastal open city in Northern China, currently has jurisdiction over 15districts including Heping, Hedong, Nankai, Hexi, Hebei, Hongqiao, Tanggu, Hangu, Dagang, Dongli, Xiqing, Jinnan, Beichen, Wuqing, Baodi, and 3 counties such as Jinghai, Ninghe and Jixian. It has a total area of 11,919.7 square kilometers, and a resident population of 1023.67 million. Table 1 shows the statistics of accidents this year in City T.

Time	Accident	Death	Injured	Population/ 10 thousand	Accident rate 0/000	Mortality rate 0/000	Injured rate 0/000
2004	10	32	27	1001	0.999	3.197	2.697
2005	9	37	25	1001	0.899	3.696	2.498
2006	1	9	3	1001	0.010	0.899	0.300
2007	9	21	5	1024	0.879	2.051	0.488

* Data derives from 2004~2007 Statistics of accident distribution in cities and provinces China in *Journal of Security and Environment*

Table 1. Statistics of accidents in recent years in City T*.

As can be seen from the table, City T is a metropolis with a good security situation, but in order to take preventive measures, it is very important and very necessary to carry out the optimization of location planning of emergency logistics base stations in City T. Therefore, in this paper, taking City T as the object, the author makes use of multi-stage location planning optimization model to study the location planning of emergency resource base stations in this city and seek a reasonable location planning program to provide a decision making basis for the future construction and development of City T.

3.2.2 Multi-stage location planning optimization model of emergency resource base station

An important role of emergency logistics base station is to provide adequate and timely emergency response resources to potential unforeseen accident or disaster sites. And the optimal planning of emergency logistics base station helps to make rational use and allocation of spaces and emergency resources, to reduce the risks the city, as well as conduce to the efficient, orderly and sustained operation of urban economy, social activities and construction activities.

The optimization of location planning of emergency resource base station includes determining reasonable position and scale of emergency resource base station. Therefore, the optimization of the location planning of emergency resource base station should mainly start with two aspects, one is to determine the appropriate scale of emergency resource base stations, and the other is to solve the problem of spatial distribution.

The first step is to use set covering model to determine the minimum number of emergency resource base stations which can meet the needs of all demand sites; and the second step is to use maximum coverage model to determine the optimal sites of the minimum number of emergency resource base stations among the options, to meet the needs of all demand sites to the maximum.

a. Scale optimization - set covering model

Coverage model is one of the most basic models of optimal planning of emergency resource base stations. The meaning of coverage refers to that the services scope of emergency resource base stations set up should be able to cover all sites requiring service. And it is one of the common goals of optimal planning of emergency logistics base station to cover all demand sites with the minimum number of emergency logistics base stations.

Set covering model is simple, but highly practical. It can be used to determine the most efficient number the emergency resource base stations covering all demand sites. Since the investment in emergency resource base stations can be quite expensive, so decision-makers need to keep a minimum number of base stations at the same time of taking providing services of necessary level to each demand site into account, therefore, they need to determine the reasonable number of emergency logistics base station under the limitation of covering distance or covering time.

The binary decision variable x_j is set as follows: When the candidate site j is selected, $x_j = 1$; otherwise $x_j = 0$. if the set of candidate sites which can cover all the demand sites i is $N_i = \{j \mid d_{ij} \le S\}$ (or $N_i = \{j \mid t_{ij} \le R\}$), the minimum number of the necessary facilities which can cover all the demand sites may be decided by set covering model:

$$\begin{aligned} \min \quad & z = \sum_{j \in J} x_j \\ s.t. \quad & \sum_{j \in N_i} x_j \ge 1 \quad \forall i \in I \\ & x_j \in (0,1) \quad \forall j \in J \end{aligned} \tag{10}$$

In which the objective function can minimize the number of base stations, the constraint 1 can ensure that each demand site is covered by at least one emergency resource base station, and it is one of the basic objectives of optimal planning of emergency resource base station. The constraint 2 limits the decision variables x_j as integer variables between (0, 1).

Set covering model is of integer linear programming model, mathematically, it is a typical NP-hard model. Generally, its solution can be obtained through relaxing integer limiting requirement against x_j, using the procedure of general linear programming, and in most cases, integer solution of general problems can be directly obtained.

b. Space layout optimization - maximum coverage model

After the first phase of finding model solution, the number of emergency resources base stations providing services to all the demand sites in the whole region can be determined. Being clear about the number of base stations, the goal of the second stage is to optimize the spatial layout of these emergency resource base stations, to enable them to meet emergency requirements.

Maximum coverage model is an extension and expansion of set covering model. This model can be used to consider the maximization of demand site value coverage (population or other indicators). Maximum coverage model was originally presented by Church and ReVelle, where d_i refers to the demand of node i, p refers to the available emergency resources. Binary variables y_i can be used to present whether the demand site is overwritten or not, when the demand site is overwritten, $y_i = 1$, otherwise $y_i = 0$.

$$\begin{aligned}
&\textbf{Maximize} \quad \sum_{i \in V} d_i y_i \\
&\textbf{subject to} \\
&\sum_{j \in W_i} x_j \geq y_i \quad (i \in V) \\
&\sum_{j \in W} x_j = p \\
&x_j \in \{0,1\} \quad (j \in W) \\
&y_i \in \{0,1\} \quad (i \in V)
\end{aligned} \tag{11}$$

Maximum coverage model can be used to seek the best possible using method of available resources, but does not guarantee to cover all demand sites. Therefore, maximum coverage model can be used to determine the optimal solution of maximum coverage on the base of the optimal solution of set coverage.

3.3 Appropriate allocation of emergency resources

3.3.1 Research background

At present, our country is in an important opportunity period for economic and social development, which is also the crucial period to implement the third-step strategic deployment of the modernization construction; therefore, the important task of our country is to maintain the long-term harmonious and stable social environment and stable and united situation. As the most important link in emergency handling, the contingency plan strengthens the research in respect of optimized resource allocation, which has very important significance for promoting the technological level of dealing with unexpected accidents and emergency management capacity of our country, guaranteeing public safety in our country and establishing reasonable and efficient contingency plans for national public safety.

The emergency resource management process of unexpected public events is in fact a set of decisions and decision implementation processes under a series of goal constraint conditions. These series of decisions and decision implementation processes mean “when and which resources at which place to allocate, and what to do”. It is necessary to invest in enhancing urban comprehensive emergency capability, which proposes the problems of optimized allocation and dispatch of limited emergency resources, and the problem solving relates to whether the limited resources can exert the greatest effect, whether the emergency rescue system can achieve the desired goal and so on. At present, the researches related to emergency resource allocation practically aim at single resource optimization, such as the emergency service vehicle dispatch or vehicle relocation problems. When the emergency service vehicle system receives the service demand, it dispatches its emergency response unit (such as police car, fire engine, ambulance and so on) to the service demand zone. After an emergency service vehicle is dispatched for service, it is necessary to study the vehicle relocation problems to guarantee the defence demand in remaining zones. Studies on the emergency resource allocation beyond service vehicles are still at the initial stage. In China, Liu Chunlin et al (1999) studied the minimized transportation time problems of emergency resource allocation in continuous consumption system and one-off consumption system [41]; Liu Chunlin et al (2000) studied the emergency problems when the required time from the depot to emergency zone is a fuzzy number. In overseas countries, Fiorucci et al (2005) studied the emergency resource allocation and scheduling problems before and after the fire through building a dynamic model; Fiedrich et al (2000) studied the problems of simultaneous resource allocation for different disaster relief tasks and so on through building a dynamic programming model [42]. At the present stage, there are fewer studies on optimized allocation of many resources under unexpected accident disasters, moreover the majority of studies only take shortest emergency time as the optimized objective of the system, and the optimized method is too simple, and lacks consideration of the complexity of the emergency process; in addition, static models are more widely used in the studies, which lack emergency resource allocation parameters reflecting the accident disaster development status.

The present research aims at enhancing the urban emergency management capacity, establishes the emergency resource allocation model in view of many accident disasters, so as to effectively integrate various emergency resources, and reduce the investment cost of emergency resource management.

3.3.2 Optimized resource allocation model

3.3.2.1 Decision model based on dynamic programming

The emergency resource allocation process is divided into *N* corresponding stages in view of the accident disaster emergency management characteristics, using the dynamic programming method, and according to the number of emergency zones (the number is supposed as *N*), based on which, a mathematical model is built, so as to optimize the emergency resource allocation. In the emergency process, a certain amount of resources are allocated to meet the emergency demand, and various parameter variables are expressed as follows.

k is the emergency stage $(k = 1,2,\cdots,N)$; x_k is the state variable in the dynamic programming model, representing the gross amount of allocated emergency resources at the k_{th} stage; u_k is the decision variable in the model, representing the alternative decision scheme; w_k represents the emergency resource demand at the k_{th} stage with given probability distribution. D_k is the set of all decision variables from 1st stage to the k_{th} stage.

Suppose that $w_1, w_2, \cdots, w_N$ are independent random variables depending on the disaster situation at emergency zones. The relationship between allocatable resource x_k, emergency resource demand w_k and emergency decision variables u_k in the emergency process is shown in Figure 3.

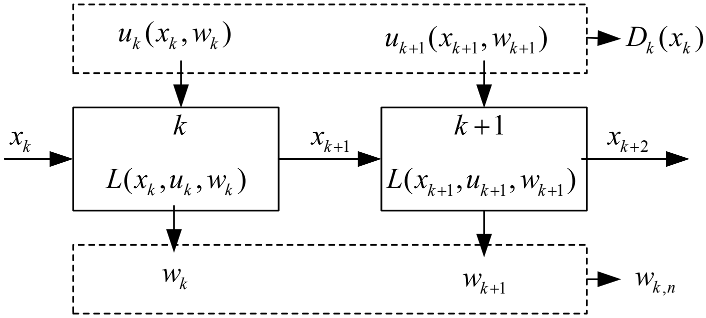

Fig. 3. The relation of proximate emergency stages based on dynamic programming.

For the $(k+1)_{th}$ stage, the dynamic system has

$$x_{k+1} = f(x_k, u_k, w_k)(k = 0,1,2,\cdots,N-1) \tag{12}$$

Where, *N* is the number of emergency zones in the emergency process.

The decision function sequence composed of the decision $u_k(x_k)(k=1,2,\cdots,N)$ at each stage is called the whole process strategy, strategy for short. Strategy refers to the set of all emergency resource allocation decisions established at any emergency stage, which is only related to the stage and state in that stage process, and is expressed as $p(x_k)$

$$p(x_k) = (u_1(x_1), u_2(x_2), \cdots, u_N(x_N)) \tag{13}$$

For the objective function *J* with given state and decisions, it can be expressed as

$$J = J(x(0), x(1), \cdots, x(N); u(0), u(1), \cdots, u(N)) \tag{14}$$

An appropriate *u* value (namely, appropriate decision sequence) is selected, so as to minimize *J* (or use other evaluation standards of *J*, such as the maximization of *J*), and optimize the objective function. Function *J* is called the criterion function.

3.3.2.2 Establishment of an optimized resource allocation model

The decision-making process at the N_{th} stage is determined using the following factors.

$$(x(0), x(1), \cdots, x(N); u(0), u(1), \cdots, u(N)) \tag{15}$$

$x_{k+1} = f(x_k, u_k, w_k)(k = 0,1,2,\cdots,N-1)$, and $x(0)$ is the known initial state, suppose that all $x(k)(k=1,2,\cdots,N)$ can be expressed as $x(0)$ and $u(k)(k=0,1,\cdots,N-1)$, so the criterion function

$$J = J(x(0), u(0), u(1), \cdots, u(N)) \tag{16}$$

x(0) is the given initial state, decision $u(k)(k=0,1,\cdots,N)$ is free variables, so the simultaneous nonlinear equation

$$\frac{\partial J}{\partial u(k)} = 0, (k = 0, 1, \cdots, N) \tag{17}$$

To solve practical problems, it is necessary to analyze and calculate the form of limit criterion function *J* in multistage decision process. In the present model

$$u(k) = u(x(k), w(k), k) \tag{18}$$

i.e., the existing decision is only the function of existing state and stochastic disturbance.

The criterion function of emergency resource allocation has Markov properties, i.e., the objective function has the following attributes

$$J = \sum_{k=0}^{N} L(x(k), u(k), w(k)) \tag{19}$$

Where, $L(x(k), u(k), w(k))$ is the objective function at each stage of the emergency process. In this model, *L* is a nonnegative function depending on the state and sum of decision items at a single stage. *J* is the objective function of the whole emergency process, equivalent to the sum of objective functions at all stages.

In general, it is known that a group of states $x(k) \in X$, and *X* is available emergency resources, then a new group of states $x(k+1)$ can be obtained according to $x(k)$ with the computing formula as

$$x(k+1) = f(x(k), u(k), w(k)) \tag{20}$$

At the same time, $J(x(k+1), k+1)$ can also be calculated

$$J(x(k+1), k+1) = L(x(k+1), u(k+1), w(k+1) + J(x(k), k) \tag{21}$$

So the total cost function of the emergency process of any systematic sample can be expressed as

$$\begin{cases} J_{k+1}(x_{k+1}) = \min \sum_{k=1}^{N-1} L_k = \min(L_{k+1}(x_{k+1}, u_{k+1}, w_{k+1}) + J_k(x_k)) \\ \text{s.t. } u_k \in p_k(x_k) \\ L_0(x_1) = 0 \\ \dfrac{\partial J}{\partial u(k)} = 0 \end{cases} \tag{22}$$

3.4 Optimal dispatching of emergency resources

3.4.1 Research background

It is necessary for the emergency command department to make the emergency resource scheduling decisions after the occurrence of sudden public events. It is necessary for emergency decision-makers to determine future resource scheduling according to the emergency resource demand situation at the present stage, and multi-stage emergency resource scheduling with the event development and changes and according to the emergency effect at the last stage and present situation. Therefore, the emergency resource scheduling is a dynamic process. Under the situation that the emergency resource site layout and allocation is known, emergency managers are concerned about the problems of how to formulate optimized scheduling scheme, guarantee the timeliness of emergency resource scheduling, and minimize the resource arrival time [43-44]. As a result, it is necessary to formulate beforehand the optimized scheme of emergency resource scheduling in the light of the specific scene of sudden public events, so as to start the emergency resource scheduling scheme as early as possible and guarantee the timeliness of emergency rescue action.

The Markov decision process can select an action from the available action set to make a decision according to the observed state at each moment. Meanwhile, the decision makers can make another new decision according to the newly observed state, and repeat such process [45]. Therefore, this section plans to study the dynamic optimization of emergency resource scheduling of sudden public events using the Markov decision process, so as to provide a basis for optimized emergency resource scheduling under sudden public events

3.4.2 Dynamic Markov decision of emergency resource scheduling

Due to a series of characteristics of sudden public events, such as nonrepeatedness, uniqueness, gradual evolution and so on, the decision-making problems for emergency resource scheduling have three main characteristics: sudden public event is dynamically changing; information about the event development is from fuzziness to clearness and from incompleteness to completeness, namely the future state is uncertain; the scheme formulated under incomplete information can be easily adjusted in time under complete information.

The optimized emergency resource scheduling can be more scientifically and reasonably realized by referring to the Markov decision analysis method, but sudden public events are not evolved and developed according to the pre-established direction. Therefore, emergency measures can be only taken according to previous experience, emergency plan and real-time information at the scene of accident (usually incomplete), and be adjusted according to unceasing improvement of the information in the emergency process.

The application of Markov decision analysis method in the optimized emergency resource scheduling process of sudden public events is shown in Figure 4. The whole decision-making process is how to select a scheme to cope with the uncertainty development state of the sudden public event, until the sudden public event is completely under control.

Basic thought of the Markov process is to infer the future state distribution according to the probability distribution of current state, and make judgment and decisions accordingly.

$X(t)$ is used to express the system state, the state sequence $\{X(t);t \in T\}$ is a stochastic process, $U_{(i)}^{m}$ is the decision set of the state i at the *n*th stage. Suppose that P_{ij} is the one-step state transition probability, $f_n(i,\pi_n)$ represents the expected total reward when the system state shifts from $X(n)=i$ at the *n*th stage to the process end; r_{ij} represents the corresponding reward when the state shifts from $X(n) = i$ to the next state $X(n+1) = j$, then there is

$$f_n(i, \pi_n) = q(i) + \sum_{j=1}^{n} p_{ij} f_{n+1}(i, \pi_{n+1}), i = 1, 2, \cdots, m; n = 1, 2, \cdots \quad (23)$$

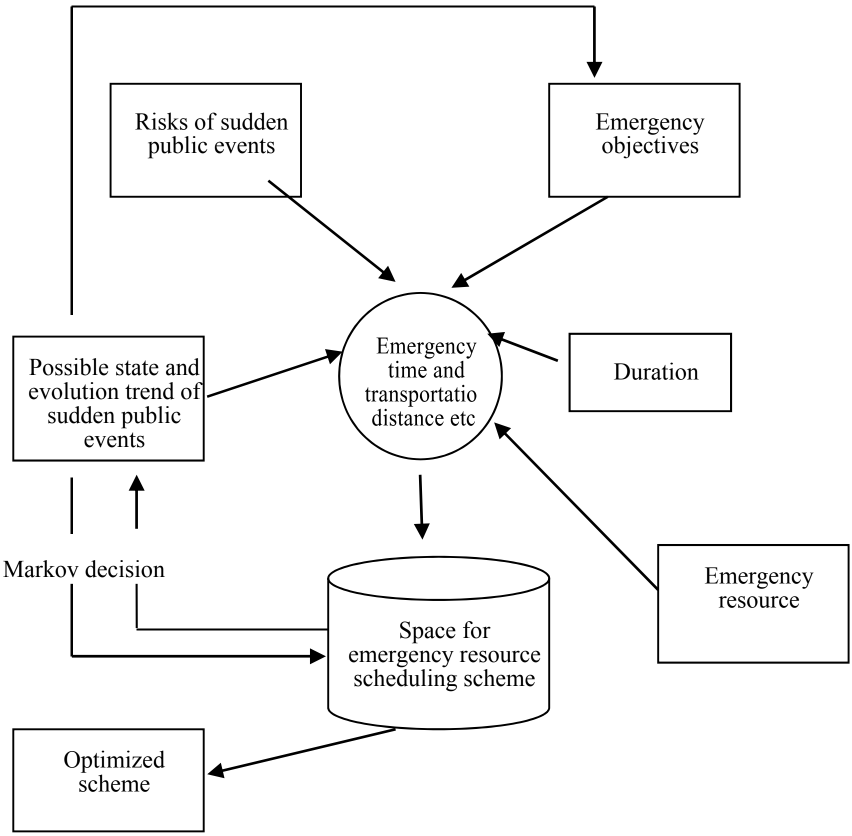

Fig. 4. Diagram of Markov decision processes in the emergency resources scheduling of the sudden public events.

π_n represents the sequence $\{\delta_n, \delta_{n+1}, \cdots\}$, $\pi_n = (\delta_n, \pi_{n+1})$ of the decision regulation δ from the *n*th stage to the process end, where δ_n is the decision regulation at the *n*th stage.

If $q(i) + \sum_{j=1}^{n} p_{ij} r_{ij}, i = 1, 2, \cdots, m$, $q(i)$ represents the expected reward when the state i shifts once, namely the real-time expected reward of the state, then the above formula can be rewritten as

$$f_n(i,\pi_n)=\sum_{j=1}^{n}p_{ij}r_{ij}+\sum_{j=1}^{n}p_{ij}f_{n+1}(i,\pi_{n+1}),i=1,2,\cdots,m;n=1,2,\cdots \quad (24)$$

This formula is the basic equation for Markov decision problems.

To research the transient state behavior the ergodic Markov chain, it is necessary to obtain its basic equations set using z transform analysis method. z transform can transform the difference equation to corresponding generalized equation. There is one-to-one correspondence between the function and its z transform, and meanwhile the primary function can be mutually converted with its z transform. Therefore, the following formulae can be obtained through z transform

$$\begin{aligned} nv+f_i&=q_i+\sum_{j=1}^{m}p_{ij}[(n-1)v+f_j]i=1,2,\cdots,m \\ nv+f_i&=q_i+\sum_{j=1}^{n}p_{ij}f_i \quad i=1,2,\cdots,m \end{aligned} \quad (25)$$

This is the basic equations set for Markov decision problems, which can be obtained through the following algorithms.

a. An initial strategy π_n is selected, a decision regulation δ_n is selected for each state $i(i=1,2,\cdots,m)$, so that its decision $u_{(i)}^{k}=\delta_n(i)$, and let $n=0$;
b. For the known strategy π_n, let $f_m^{(n)}=0$, the corresponding strategy profit $v^{(n)}$ and corresponding value $f^{(n)}(i=1,2,\cdots,m;n=0,1,2,\cdots)$ can be obtained through solving the basic equations set for Markov decision problems;
c. A new strategy regulation δ_{n+1} is sought using the $f_m^{(n)}$ obtained from the last strategy, so that for each state i,

$$q_i^{\delta_{n+1}(i)}+\sum_{j=1}^{n}p_{ij}^{\delta_{n+1}(i)}f_j^{(n)}-f_i \quad (26)$$

achieves its maximal value, and a new strategy π_{n+1} is obtained accordingly;

d. If the obtained strategy π_{n+1} is completely equal to the strategy π_n obtained through the last iteration, namely $\pi_{n+1}=\pi_n$, then the iteration is stopped, and the optimized strategy is obtained. Otherwise, return to step 2 and let n = n+1.

4. Case study

4.1 Case study – Emergency resources demand prediction using case-based reasoning

The prediction process above can be applied not only in the prediction on emergency resource demand for the public emergencies that have not yet happen, but also in the prediction on emergency resource demand for occurred public emergencies.

Given that the city T plans to conduct a prediction on the demand of emergency resource when the earthquake occurs, and there are four cases for this type of Emergency response in the case library, expressing as $C=(C_1, C_2, C_3, C_4)$, and each case includes the demand information of quantity, quality and type of corresponding emergency resource, as shown in Table 2.

Case	Emergency resource type	Emergency resource quantity	Emergency resource quality
	Tent	100,000	Excellent
C_1	Clean water	150,000kg	Excellent
	Blood plasma	2000 ml	Excellent
	Instant noodle	140,000	Excellent
C_2	Quilt	100,000	Excellent
	Cotton dress	100,000	Excellent
	Stretcher	5000	Excellent
C_3	Tent	150,000	Excellent
	Food	200,000 kg	Excellent
	Cloth	120,000	Excellent
C_4	Drinking water	200,000 kg	Excellent
	Fresh vegetables	150,000 kg	Excellent

Table 2. Simplified Instance of Case Information Library.

Given that the emergency rescue plans for this type of Emergency response are the same. Through the risk analysis, five characteristic factors reflecting the characteristics of Emergency response are selected, meaning that the characteristic factor set B is composed of hazard intensity, disaster-affected population, direct economic losses, stricken area and duration time of disaster, and the membership function of four cases to five characteristic factors is as follows respectively:

$$\begin{aligned} n_{C_1}(b) &= \frac{0.8}{b_1}+\frac{0.7}{b_2}+\frac{0.4}{b_3}+\frac{0.3}{b_4}+\frac{0.6}{b_5} \\ n_{C_2}(b) &= \frac{0.6}{b_1}+\frac{0.6}{b_2}+\frac{0.8}{b_3}+\frac{0.9}{b_4}+\frac{0.7}{b_5} \\ n_{C_3}(b) &= \frac{0.4}{b_1}+\frac{0.6}{b_2}+\frac{0.8}{b_3}+\frac{0.8}{b_4}+\frac{0.6}{b_5} \\ n_{C_4}(b) &= \frac{0.9}{b_1}+\frac{0.8}{b_2}+\frac{0.8}{b_3}+\frac{0.8}{b_4}+\frac{0.7}{b_5} \end{aligned} \tag{27}$$

Given that an Emergency response occurs now, and it needs to conduct a prediction on its emergency resource demands. Given that the emergency resource demand prediction plan for this Emergency response expressed as T, and its membership function can expressed as the formula below:

$$n_T(b) = \frac{0.5}{b_1} + \frac{0.7}{b_2} + \frac{0.7}{b_3} + \frac{0.8}{b_4} + \frac{0.6}{b_5} \tag{28}$$

It can be calculated that $\overline{n}(b_1)$ =0.68, $\overline{n}(b_2)$ =0.68, $\overline{n}(b_3)$ =0.7, $\overline{n}(b_4)$ =0.65 and $\overline{n}(b_5)$ =0.65, further it can be obtained that $\delta(b_1)$ =0.192, $\delta(b_2)$ =0.083, $\delta(b_3)$ =0.173, $\delta(b_4)$ =0.05 and $\delta(b_5)$ =0.05.

Therefore, the weight value of each characteristic factor can be calculated as follows: w_1=0.35, w_2=0.15, w_3=0.32, w_4=0.09 and w_5=0.09. According to the similarity calculation method, the similarity of each case is calculated as follows: $sim(T, C_1)$=0.36, $sim(T, C_2)$=0.66, $sim(T, C_3)$=0.86 and $sim(T, C_4)$=0.66. All above are shown in Table 2, and the similarity of each case is ordered as follows:

$$sim(T, C_1) < sim(T, C_2) = sim(T, C_4) < sim(T, C_3) \tag{29}$$

It can be seen from the calculations above that this Emergency response is similar to the case C_3 in the case library, so that the emergency resource demand prediction results of this Emergency response are similar to that of the case C_3. Consequently, the conclusions of prediction on this emergency resource demand can be drawn by correcting and adjusting the emergency resource demand analysis results of the case C_3.

Attribute No.	Weight of each attribute	Case 1	Case 2	Case 3	Case 4
Disaster intensity	0.35	Extra large	Large	Large	Large
Disaster-affected population (10,000 peoples)	0.15	0.8	0.5	0.4	0.6
Direct economic losses (10,000 yuan)	0.32	100	11	10.6	9
Stricken area (km^2)	0.09	5	3	2	2
Duration time of disaster (day)	0.09	10	6	6	5
Similarity with current case		0.36	0.66	0.86	0.66

Table 3. Characteristic Factor Information of each Case.

4.2 Case study – Application of multi-stage location planning model in optimizing location of emergency resource base stations

In this section, the author makes an optimization of location planning of emergency resource base stations in City T according to the specific circumstances of City T. City T has jurisdiction over 15districts including Heping, Hedong, Nankai, Hexi, Hebei, Hongqiao, Tanggu, Hangu, Dagang, Dongli, Xiqing, Jinnan, Beichen, Wuqing, Baodi, and 3 counties such as Jinghai, Ninghe and Jixian.. The distribution of major districts and counties (the six districts including Heping, Hedong, Nankai, Hexi, Hebei, Hongqiao are called as a unified urban) is shown in Figure 5.

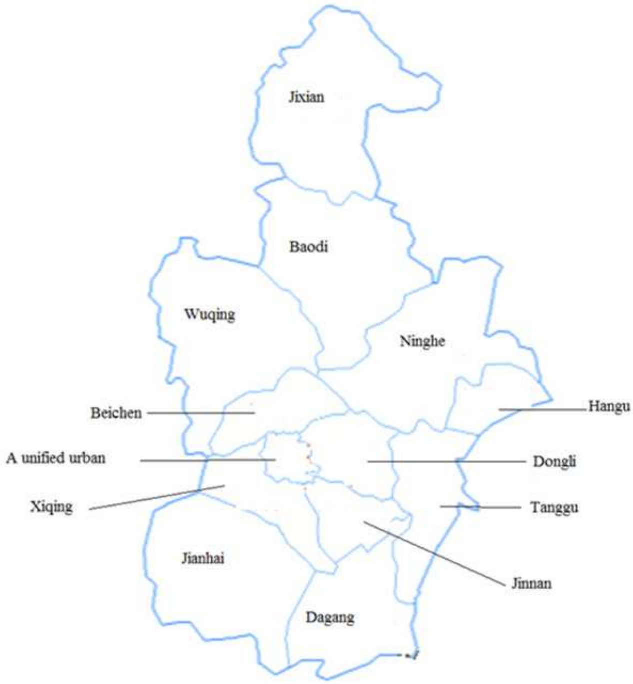

Fig. 5. Administrative Map of City T.

For the sake of computational convenience, and the visual presentation method, in this paper, distances between these administrative districts are presented with straight-line distances, and the central areas of these administrative districts with high concentration of population are determined as the ends of distance calculations, Table 4 shows the straight-line distances between these districts and the population distribution of various administrative districts.

Distance (km)	Urban district	Tanggu	Hangu	Dagang	Dongli	Xiqing	Jinnan	Beichen	Wuqing	Baodi	Jixian	Ninghe	Jinghai
Urban district	0	39.3	53	36.3	9.7	17.3	20.3	13.3	32.3	67	104.3	57	31.7
Tanggu	39.3	0	27.7	26	30	56.7	23.3	49.3	65.3	81.7	115.3	36	63.3
Hangu	53	27.7	0	60.7	50.7	69.3	45.7	58	67.3	61	95	8.7	83.3
Dagang	36.3	26	60.7	0	28.7	49.3	17.3	49.3	68.3	96.7	132.7	61.3	46.7
Dongli	9.7	30	46	28.7	0	26.7	12	21.7	40	70	106.7	50.7	37.3
Xiqing	17.3	56.7	69.3	49.3	26.7	0	36	13.3	26.7	68.7	106	72	24
Jinnan	20.3	23.3	45.7	17.3	12	36	0	32.7	51.7	80	116.7	52	40
Beichen	13.3	49.3	58	49.3	21.7	13.3	32.7	0	19.3	54	94.7	60	36
Wuqing	32.3	65.3	67.3	68.3	40	26.7	51.7	19.3	0	44	80	66.7	50
Baodi	67	81.7	67.3	96.7	70	68.7	80	54	44	0	37.3	61	92.7
Jixian	104.3	115.3	95	132.7	106.7	106	116.7	94.7	80	37.3	0	87.3	130
Ninghe	57	36	8.7	61.3	50.7	72	52	60	66.7	61	87.3	0	88
Jinghai	31.7	63.3	83.3	46.7	37.3	24	40	36	50	92.7	130	88	0
Population (10000)	389	45	17	32	30.4	31	42	34	82	65	78	36	50

Table 4. The straight-line distances between centers of various administrative districts.

The 15 administrative districts are respectively defined in Table 5. To divide the distances by the speed of 80km / h, the travel times are listed in Table 6.

Urban district	Tanggu	Hangu	Dagang	Dongli	Xiqing	Jinnan	Beichen	Wuqing	Baodi	Jixian	Ninghe	Jinghai
A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13

Table 5. Signs of various administrative districts.

Time (min)	Urban	Tanggu	Hangu	Dagang	Dongli	Xiqing	Jinnan	Beichen	Wuqing	Baodi	Jixian	Ninghe	Jinghai
Urban	0	29.48	39.75	27.23	7.28	12.98	15.23	9.98	24.23	50.25	78.23	42.75	23.78
Tanggu	29.48	0	20.78	19.50	22.50	42.53	17.48	36.98	48.98	61.28	86.48	27.00	47.48
Hangu	39.75	20.78	0	45.53	38.03	51.98	34.28	43.50	50.48	45.75	71.25	6.53	62.48
Dagang	27.23	19.50	45.53	0	21.53	36.98	12.98	36.98	51.23	72.53	99.53	45.98	35.03
Dongli	7.28	22.50	34.50	21.53	0	20.03	9.00	16.28	30.00	52.50	80.03	38.03	27.98
Xiqing	12.98	42.53	51.98	36.98	20.03	0	27.00	9.98	20.03	51.53	79.50	54.00	18.00
Jinnan	15.23	17.48	34.28	12.98	9.00	27.00	0	24.53	38.78	60.00	87.53	39.00	30.00
Beichen	9.98	36.98	43.50	36.98	16.28	9.98	24.53	0	14.48	40.50	71.03	45.00	27.00
Wuqing	24.23	48.98	50.48	51.23	30.00	20.03	38.78	14.48	0	33.00	60.00	50.03	37.50
Baodi	50.25	61.28	50.48	72.53	52.50	51.53	60.00	40.50	33.00	0	27.98	45.75	69.53
Jixian	78.23	86.48	71.25	99.53	80.03	79.50	87.53	71.03	60.00	27.98	0	65.48	97.50
Ninghe	42.75	27.00	6.53	45.98	38.03	54.00	39.00	45.00	50.03	45.75	65.48	0	66.00
Jinghai	23.78	47.48	62.48	35.03	27.98	18.00	30.00	27.00	37.50	69.53	97.50	66.00	0

Table 6. The travel times between centers of various administrative districts.

Table 7-9 show the minimum numbers of emergency resource base stations covering all the administrative districts and specific sites, in the case of that emergency response time standards are 30min, 45min and 60min respectively.

1. When the emergency response time standard is set as 30min

District	Districts within a 30-min drive
A1	A2,A4,A5,A6,A7,A8,A9,A13
A2	A1,A3,A4,A5,A7,A12
A3	A2,A12
A4	A1,A2,A5,A7
A5	A1,A2,A4,A6,A7,A8,A9,A13
A6	A1,A5,A7,A8,A9,A13
A7	A1,A2,A4,A5,A6,A8,A13
A8	A1,A5,A6,A7,A9,A13
A9	A1,A5,A6,A8,
A10	A11
A11	A10
A12	A2,A3

Table 7. The coverage for different administrative districts in T=30min.

Using WinQSB to find the solution of set covering model, the optimal solution of z = 4 is obtained, that is, to cover all demand sites, four emergency resource base stations are necessary. Then using MCLP model, and having the p-value increase continuously from 1 to 4, using WinQSB, solution of the model can be obtained as follows:

When p = 1, the solution is: A5 = 1, Y1 = Y2 = Y4 = Y6 = Y7 = Y8 = Y9 = Y13 = 1, z = 705, it means that if an emergency resource base station is built in the Dongli District, it can cover the urban district, Tanggu, Dagang, Xiqing, Jinnan, Beichen, Wuqing and Jinghai in 30 minutes, the total number of the population in these districts is 7.05 million.

When p = 2, the solution is: A1 = A2 = 1, Y1 = Y2 = Y3 = Y4 = Y5 = Y6 = Y7 = Y8 = Y9 = Y12 = Y13 = 1, z = 788.4, it means that if two emergency resource base stations are built in the urban district and Tanggu respectively, they can cover the urban district, Tanggu, Hangu, Dagang,Dongli, Xiqing, Jinnan, Beichen, Wuqing, Ninghe and Jinghai in 30 minutes, the total number of the population in these districts is 7.884 million.

When p = 3, the solution is A1 = A2 = A10 = 1, Y1 = Y2 = Y3 = Y4 = Y5 = Y6 = Y7 = Y8 = Y9 = Y11 = Y12 = Y13 = 1, z = 866.4, it means that if two emergency resource base stations are built in the urban district, Tanggu and Baidi respectively, they can cover the urban district, Tanggu, Hangu, Dagang, Dongli, Xiqing, Jinnan, Beichen, Wuqing, Jixian County, Ninghe and Jinghai in 30 minutes, the total number of the population in these districts is 8.664 million.

When p = 4, the solution is A2 = A5 = A10 = A11 = 1, Y1 = Y2 = Y3 = Y4 = Y5 = Y6 = Y7 = Y8 = Y9 = Y10 = Y11 = Y12 = Y13 = 1, z = 931.4, it means that if four emergency resource base stations are built in Tanggu,Dongli, Baidi and Jixian County respectively, they can cover all administrative districts in 30min, the total number of the population in these districts is 9.314 million.

2. When the emergency response time standard is set as 45min

District	Districts within a 45-min drive
A1	A2,A3,A4,A5,A6,A7,A8,A9,A12,A13
A2	A1,A3,A4,A5,A6,A7,A8,A12
A3	A1,A2,A5,A7,A8,A12
A4	A1,A2,A5,A6,A7,A8,A13
A5	A1,A2,A3,A4,A6,A7,A8,A9,A12,A13
A6	A1,A2,A4,A5,A7,A8,A9,A13
A7	A1,A2,A3,A4,A5,A6,A8,A9,A12,A13
A8	A1,A2,A3,A4,A5,A6,A7,A9,A10,A12,A13
A9	A1,A5,A6,A7,A8,A10,A13
A10	A8,A9,A11,A13
A11	A10
A12	A1,A2,A3,A5,A7,A8

Table 8. The coverage for different administrative districts in T=45min.

Through the same calculation process as above, the optimal solution of z = 2 is obtained, that is, to cover all demand sites, two emergency resource base stations are necessary. Then using MCLP model and having the p-value increase continuously from 1 to 2, using WinQSB, solution of the model can be obtained as follows:

When p = 1, the solution is A8 = 1, Y1 = Y2 = Y3 = Y4 = Y5 = Y6 = Y7 = Y9 = Y10 = Y12 = Y13 = 1, z = 819.4, it means that if a emergency resource base station is build in Beichen, it can cover the urban district, Tanggu, Hangu and Dagang, Dongli, Xiqing, Jinnan, Wuqing, Baodi, Ninghe and Jinghai within 45min, the total number of the population in these districts is 8.194 million.

When p = 2, the solution is A8 = A10 = 1, Y1 = Y2 = Y3 = Y4 = Y5 = Y6 = Y7 = Y8 = Y9 = Y10 = Y11 = Y12 = Y13 = 1, z = 931.4, it means that if two emergency resource base stations are built in Beichen and Baodi respectively, they can cover all the administrative regions in 45-min, the total number of the population in these districts is 9.314 million.

3. When the emergency response time standard is set as 60 min

District	Districts within a 60-min drive
A1	A2,A3,A4,A5,A6,A7,A8,A9,A10,A12,A13
A2	A1,A3,A4,A5,A6,A7,A8,A9,A12,A13
A3	A1,A2,A4,A5,A6,A7,A8,A9,A10,A12
A4	A1,A2,A3,A5,A6,A7,A8,A9,A12,A13
A5	A1,A2,A3,A4,A6,A7,A8,A9,A10,A12,A13
A6	A1,A2,A3,A4,A5,A7,A8,A9,A10,A12,A13
A7	A1,A2,A3,A4,A5,A6,A8,A9,A10,A12,A13
A8	A1,A2,A3,A4,A5,A6,A7,A9,A10,A12,A13
A9	A1,A2,A3,A4,A5,A6,A7,A8,A10,A11,A12,A13
A10	A1,A3,A5,A6,A7,A8,A9,A11,A12
A11	A9,A10
A12	A1,A2,A3,A4,A5,A6,A7,A8,A9,A10

Table 9. The coverage for different administrative districts in T=60min.

Through the same calculation process as above, the optimal solution of z = 2 is obtained, that is, to cover all demand sites, two emergency resource base stations are necessary. Then using MCLP model and having the p-value increase continuously from 1 to 2, using WinQSB, solution of the model can be obtained as follows:

When p = 1, the solution is A9 = 1, Y1 = Y2 = Y3 = Y4 = Y5 = Y6 = Y7 = Y8 = Y10 = Y11 = Y12 = Y13 = 1, z = 849.4, it means that if a emergency resource base station is build in Wuqing, it can cover the urban district, Tanggu, Hangu, Dagang, Dongli, Xiqing, Jinnan, Beichen, Baodi, Jixian County, Ninghe and Jinghai within 60min, the total number of the population in these districts is 8.494 million.

When p = 2, the solution is A2 = A9 = 1, Y1 = Y2 = Y3 = Y4 = Y5 = Y6 = Y7 = Y8 = Y9 = Y10 = Y11 = Y12 = Y13 = 1, z = 931.4, it means that if two emergency resource base stations are built in Tanggu and Wuqing respectively, they can cover all the administrative regions in 60 min, the total number of the population in these districts is 9.314 million.

4. Analysis of the result

30min 45min 60min

Fig. 6. Results Map of City T.

Comparing the above results under the three emergency response time standards, we can find that:

1. Though the solutions of set covering model and maximum coverage model, it is found that within the area of a 30-min drive（response time standard）, four emergency resource base stations are the most reasonable and can meet the demand, and when the number of base stations is less than 4, the emergency demand can not be met, and when the number is more than 4, unnecessary waste and redundant coverage will be made, and through MCLP model, the construction site of the four base stations can be determined as Tanggu, Dongli, Baodi and Jixian.
2. When the emergency response time standards are set as 45min and 60min, the result shows a maximum of two emergency resources is enough to cover all administrative regions of City T, but for different time standards, the base stations should be built in different districts, when the time standard is 45min, they should be built in Beichen and Baodi, and when the time standard is 60min, they should be built in Tanggu and Wuqing.
3. Because this result is obtained through simplifying the actual problems appropriately, can provide a reference for the actual decision-making, but there may be some errors, so the research of planning method more precise and close to the actual is required.

4.3 Case study – Appropriate allocation of emergency resources

It is supposed that there are 4 dangerous emergency zones in the emergency process, namely $N = 4$; total available amount of emergency resources is 12, namely $X = 12$, and X represents the total amount of available resources. Risk value when each scene is allocated with different amounts of emergency resources is listed in Table 10.

Emergency resources are dispatched according to the emergency resource allocation model, so as to achieve the optimization objective of minimizing the sum of risk values at various emergency zones in the following processing steps:

1. Suppose that the emergency response process can be divided into 4 stages, namely 4 emergency zones, i.e. $k = 1,2,3,4$;
2. The emergency resource allocation objective at each stage is L_k, and the total emergency objective is expressed as formula (7) when the emergency stage reaches $k+1$;
3. There is only one state variable $x(k)$ in the example, and $\sum_{k=1}^{N} x(k) = 12$;

Emergency resource amount	Risk value of zones			
	A	B	C	D
2	20	31	27	38
3	16	26	25	35
4	11	21	23	33

Table 10. Emergency resource amount and the risk value of zones.

4. Suppose that in the available allocation scheme, the emergency resource amount provided for each emergency zone changes from 2 to 4, namely $2 \le u_k \le 4$;
5. In that case, formula $x(k+1) = f(x(k), u(k), w(k))$ can be written as $x_{k+1} = u_k + x_k$;
6. Parameters are substituted into formula (8) to obtain

$$\begin{cases} J_{k+1}(x_{k+1}) = \min\limits_{2 \le u_k \le 4} \sum\limits_{k=1}^{N-1} L_k = \\ \qquad \min\limits_{2 \le u_k \le 4} (L_{k+1}(x_{k+1}, u_{k+1}, w_{k+1}) + J_k(x_k)) \\ J_0(x_1) = 0 \end{cases}$$

The optimized emergency resource allocation is calculated under the supposed scene of accidents with the mathematical mode of optimized emergency resource allocation, so as to obtain the optimized allocation result.

For the risk zone A, alternative resource allocation decision is 2-4, corresponding total risk value is from 20 to 11, so risks can be minimized to 11 with the decision 4 in the risk zone A (Table 11). The optimized decision scheme of zones B, C and D can be obtained with the same method (Table 12-14). Under 4 dangerous scenes, optimized allocation of limited resources is 4 in zone A, 4 in zone B, 2 in zone C and 2 in zone D, thus the total risk value is reduced to 97.

x_1	Corresponding risk value of zone A at the first stage of the resource allocation strategy u_1			$\min\sum L_1$
	2	3	4	
2	20+0	-	-	20
3	20+0	16+0	-	16
4	20+0	16+0	11+0	11

Note: x_1 is the corresponding amount of resource demand under each resource allocation decision at the first stage; $\min\sum L_1$ is the minimum risk value corresponding to different decisions at the first stage.

Table 11. Resource allocation strategies and corresponding risk value of zone A (the first stage).

x_2	Corresponding risk value of zone B at the second stage of the resource allocation strategy u_2			$\min\sum L_2$
	2	3	4	
4	31+20	-	-	51
5	31+16	26 + 20	-	46
6	31+11	26 + 16	21+20	42
7	31+11	26 + 11	21+16	37
8	31+11	26+ 11	21+11	32

Note: x_2 is the corresponding amount of resource demand under each resource allocation decision at the second stage; $\min\sum L_2$ is the minimum risk value corresponding to different decisions at the second stage.

Table 12. Resource allocation strategies and corresponding risk value of zone B (the second stage).

x_3	Corresponding risk value of zone C at the third stage of the resource allocation strategy u_3			$\min\sum L_3$
	2	3	4	
8	27 + 42	25 + 46	23 + 51	69
9	27 + 37	25 + 42	23+46	64
10	27 + 32	25 + 37	23+42	59

Note: x_3 is the corresponding amount of resource demand under each resource allocation decision at the third stage; $\min\sum L_3$ is the minimum risk value corresponding to different decisions at the third stage.

Table 13. Resource allocation strategies and corresponding risk value of zone C (the third stage).

x_4	Corresponding risk value of zone D at the fourth stage of the resource allocation strategy u_4			$\min\sum L_4$
	2	3	4	
12	38 + 59	35 + 64	33 + 69	97

Note: x_4 is the corresponding amount of resource demand under each resource allocation decision at the fourth stage; $\min\sum L_4$ is the minimum risk value corresponding to different decisions at the fourth stage.

Table 14. Resource allocation strategies and corresponding risk value of zone D (the fourth stage).

4.4 Case study – Optimal dispatching of emergency resources

In order to validate the dynamic optimization process of emergency resource scheduling of sudden public events with the Markov decision process, here the rationality and practicability of dynamic optimization method of emergency resource scheduling based on the Markov decision process is proved through analysis and explanation by examples.

Now it is supposed that an earthquake disaster takes place in a city, which is likely to cause two secondary disasters S_1 and S_2, namely the state space of this earthquake disaster is $S = \{S_1, S_2\}$. where, S_1 and S_2 represent the initial event S, namely secondary accidents are likely to be obtained from evolution of the earthquake disasters.

Then it is supposed that only one emergency resource R is required in emergency of this sudden public event, and the emergency time standard T is 2 time units. So long as enough amounts of emergency resources is transported to sudden public event sites within the standard time under the state of an event, then the sudden public event can be under control. If the amount of resource R transported to the scene of accident is insufficient, then the sudden public event can only be partially controlled (expressed as the availability of the emergency resources a), and the range of values of a is 0%~100%. It is also supposed that the relationship between the demand and the availability of the emergency resource R is shown in Table 15.

State S	Demand of the emergency resource R	Availability a/%
S_1	120	100
	80	80
S_2	200	100
	120	80
	80	40

Table 15. Relationship between the demand and the availability of the resources under different states of S.

It is supposed that 4 emergency resource sites around the sudden public events can cover this event site in 2 time units, as shown in Figure 7. As can be seen from the Figure 7, only the site A is in 1 time unit, while the site B is in the space of 1.5 time units, and both the site C and site D are in 2 time units. The amount of stored emergency resources at each site is also shown in the Figure 7.

Now it is stipulated that the emergency satisfaction is defined as the emergency success. Under the circumstances, the emergency resource site A is closest to the scene of accident X, therefore it is necessary to choose the site A, so as to satisfy the shortest emergency time. When the accident is under the state of S_1, 80 units of emergency resource R are transported from the emergency resource site A to the event site X, so the availability of the resources is only 80% under the state of S_1, which is unable to completely satisfy the emergency demand. Under the circumstances, it is necessary to be supported by the sites B, C and D. When the sudden public event is under the state of S_1, 40 units of emergency resources can be transported from the emergency resource sites B, C and D to the site X, so that the total accumulated amount achieves 120 units, and the amount of resources achieves the availability of 100%; but it is necessary to transport 120 units of resources from the sites B, C and D to the site X under the state of S_2, so that the total accumulated amount achieves 200 units, and the availability achieves 100%.

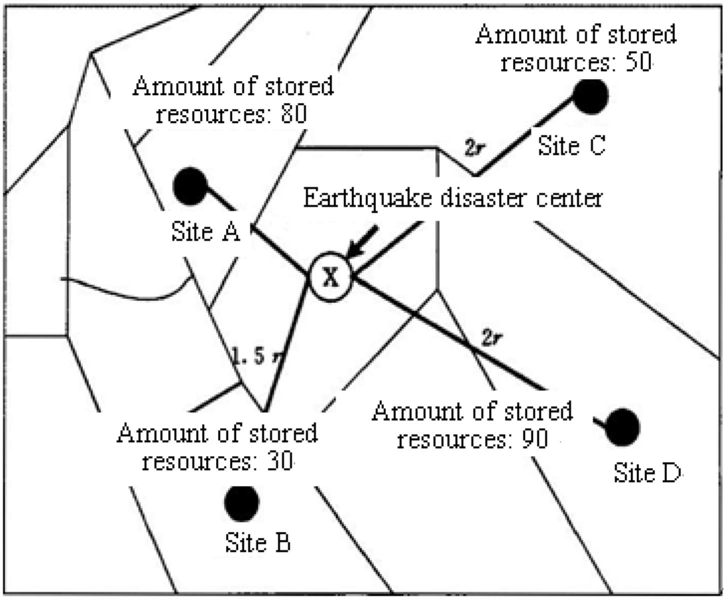

Fig. 7. Distribution map of the emergency resources sites.

Therefore, the state space in this example is $S = \{S_1, S_2\}$, the decision space can be expressed as the scheduling scheme, and the reward can be expressed as the cost or scheduling duration, as shown in Table 16.

			Site A	Site B	Site C	Site D	Total	Availability
Amount of stored emergency resources at each site			80	30	50	90	250	
State S_1	Scheme I	Transportation quantity	80	30	0	10	120	100%
		Cost	10	30	0	30	70	
	Scheme II	Transportation quantity	80	30	10	0	120	100%
		Cost	10	30	20	0	60	
State S_2	Scheme III	Transportation quantity	80	30	20	70	200	100%
		Cost	10	30	40	150	230	
	Scheme IV	Transportation quantity	80	30	50	40	200	100%
		Cost	10	30	80	100	220	

Table 16. Statistical table of the transportation quantity and cost.

The state transition probability of sudden public events can be obtained using the Domino effect analysis method, as shown in Table 17. This process is complex, so it is unnecessary to go into details in this section.

State *i*	Decision	Transition probability		Reward		Expected timely reward
	$V_{(i)}^{K}=\delta(i)$	$p_{i1}^{\delta(i)}$	$p_{i2}^{\delta(i)}$	$r_{i1}^{\delta(i)}$	$r_{i2}^{\delta(i)}$	$q_{i}^{\delta(i)}$
S_1	*Scheme I*	0.3	0.7	-10	-3	-5.1
	Scheme II	0.8	0.2	-12	-11	-11.8
S_2	*Scheme III*	0.6	0.4	-9	-8	-8.6
	Scheme IV	0.5	0.5	-4	-5	-4.5

Note: The reward uses emergency consumption time, and is negative as a consequence.

Table 17. The transition probability and reward.

The solution process is as follows:

There are two states in this case, and two decisions under each state, namely the scheduling schemes. $u_{(1)}^{1}$ represents selecting the scheduling scheme I when the event is under the state of *S1*; $u_{(1)}^{2}$ represents selecting the scheduling scheme II when the event is under the state of *S2*; $u_{(2)}^{1}$ represents selecting the scheduling scheme III when the event is under the state of *S2*; $u_{(2)}^{2}$ represents selecting the scheduling scheme IV when the event is under the state of *S2*.

Expected timely reward: $q_1^1=\sum_{j=1}^{m}p_{ij}r_{ij}=0.3\times(-10)+0.7\times(-3)=-5.1$, likewise $q_1^2=-11.8$, $q_2^1=-8.6$, $q_2^2=-4.5$.

In the first step, select the initial strategy π_0; let $\delta_0(1)=u_{(1)}^{1}$, $\delta_0(2)=u_{(2)}^{1}$, that is, select the scheduling scheme I under the state of *S1*, and select the scheduling scheme II under the state of *S2*, then there is $P=\begin{bmatrix}0.3 & 0.7\\ 0.6 & 0.4\end{bmatrix}$, $Q=\begin{bmatrix}- & 5.1\\ - & 8.6\end{bmatrix}$.

In the second step, calculate the fixed value, and estimate the initial strategy

$$\begin{cases} v+f_1=-5.1+0.3f_1+0.7f_2 \\ v+f_2=-8.6+0.6f_1+0.4f_2 \end{cases},$$

let $f_2=0$, $v^{(0)}=-6.99$, $f_1^{(0)}=2.69$, $f_2^{(0)}=0$ is obtained through solving the equations set.

The third step is the strategy improvement program, in which the improvement strategy π_1 is obtained.

For the state *S₁*, select a strategy $u_1^{(k)}$, so as to maximize $q_1^k + p_{11}^k f_1^{(0)} + P_{12}^k f_1^{(0)}$, that is

$$\begin{cases} -5.1+0.3\times 2.69+0.7\times 0-2.69=-6.99 \\ -11.8+0.8\times 2.69+0.2\times 0-2.69=-12.388 \end{cases}$$

Select the strategy $u_{(1)}^1$. Scheme I is used for emergency resource scheduling under the state of S_1.

For the state S_2, select a strategy $u_2^{(k)}$, so as to maximize $q_2^k + p_{21}^k f_1^{(0)} + p_{22}^k f_2^{(0)}$, that is

$$\begin{cases} -8.6+0.6\times 2.69+0.4\times 0-0=-6.99 \\ -4.5+0.5\times 2.69+0.5\times -0=-3.15 \end{cases}$$

Select the strategy $u_{(2)}^2$. Scheme IV is used for emergency resource scheduling under the state of S_2.

The improvement strategy is obtained as $\delta_1(1)=u_{(1)}^1$, $\delta_1(2)=u_{(2)}^2$ from the above computing results. The strategy π_1 is different from π_0, so no optimized strategy is obtained and it is necessary to go on iteration.

The fourth step is fixed value operation for the purpose of obtaining $v^{(1)}$, $f_1^{(1)}$, $f_2^{(1)}$

$$\begin{cases} v^{(1)}+f_1^{(1)}=-5.1+0.3f_1^{(1)}+0.7f_2^{(1)} \\ v^{(1)}+f_2^{(1)}=-4.5+0.5f_1^{(1)}+0.5f_2^{(1)} \end{cases}$$

Let $f_2^{(1)}=0$, then $v^{(1)}=-4.75$, $f_1^{(1)}=-0.5$, $f_2^{(1)}=0$ is obtained through solving the equations set.

In the fifth step, seek the improvement strategy π_2.

For the state S_1, there is

$$\begin{cases} -5.1+0.3\times(-0.5)+0.7\times 0+0.5=-4.75 \\ -11.8+0.8\times(-0.5)+0.2\times 0+0.5=-11.7 \end{cases}$$

So the strategy $u_{(1)}^1$ is still taken.

For the state S_2, there is

$$\begin{cases} -8.6+0.6\times(-0.5)+0.4\times 0-0=-8.9 \\ -4.5+0.5\times(-0.5)+0.5\times 0-0=-4.75 \end{cases}$$

So the strategy $u_{(2)}^2$ is still taken.

As a result, $\delta_1(1)=u_{(1)}^1$, $\delta_1(2)=u_{(2)}^2$ is obtained, which is exactly the same as the previous iteration results, so the optimized strategy is obtained as π_1. That is, take the scheduling scheme I when the sudden event is under the state of S_1, and take the scheduling scheme IV when the sudden event is under the state of S_2.

5. Conclusion and future researches

When we design an emergency rescue system, we need to coordinate the manpower with the financial, material resources. It is a complicated process to optimally allocate various elements within a system. It involves a wide range of contents. Repeated researches should be made on several theories and methods. Designing of an emergency rescue system covers the following four aspects which have been cross-linked each other essentially, that are 1) Demand Forecasting of Emergency Resources;2) Optimal Site Selection for the Base Station of Emergency Resources;3) Appropriate Allocation of Emergency Resources;4) Optimal Dispatching of Emergency Resources. Here, it proposed the overall and detailed methods to fulfill these four aspects.

In the future it is necessary to develop a computer system, so that these methods can adapt to the dynamic optimization process of emergency resource scheduling scheme under complex conditions such as many times of derivation and many kinds of resources etc., and it can more greatly satisfy the actual need.

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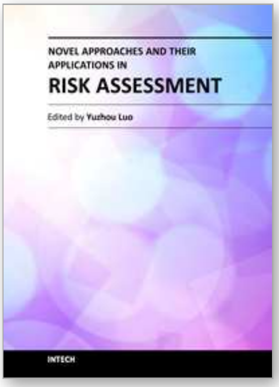

Novel Approaches and Their Applications in Risk Assessment

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