Research on the Evolution Law and Response Capability Based on Resource Allocation Model of Unconventional Emergency

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***Abstract*—Social unconventional emergencies not only bring disaster to human life and living environment, but also cause losses to the country and the people. What's more, their occurrence tends to cause series of chain reactions and inspire lots of social problems, thus likely to break the social balance, and lead to national instability and social disharmony. In this paper, "concern degree model" is introduced in the research of the evolution law of social unconventional emergencies to find the intrinsic relationship between events and phenomena, which portrays the evolution mechanism of emergencies in a more scientific way. In the assessment study of the response capability of security precaution system, based on the latest approaches of system performance assessment, combined with the concept of concern degree, the response capability of security precaution system in social unconventional emergencies is scientifically assessed. The research provides a new idea in finding the evolution law of unconventional emergencies, and makes the assessment of response capability of security system more objective and scientific. Powerful support is provided in making emergency decisions in unconventional emergencies. A grey-prediction-based emergency resource allocation model is proposed according to the reality and problems of current research on emergency resource allocation and scheduling under unconventional social emergency. This model can be used to optimize the year's total amounts of emergency resource requirements.**

***Index Terms*—social unconventional emergency, evolution model of public emergency, concern degree, security precaution system, emergency resource allocation, emergency resource scheduling, grey prediction model**

I. INTRODUCTION

Since China's reform and opening, the plurality of interest subjects, diversity of interests appeal and complexity of social mentality lead to psychological imbalance in some people. Compared with the traditional crises or disasters, human being lack in-depth scientific understanding for evolution law of those unconventional emergencies, and in practice there is also a lack of quantitative assessment methods to the whole system' capability to cope with the risks. The practice of emergency response for social unconventional events shows that it's particularly important how to control the emergency response plan at the earliest time according to the nature of events and extent of damage, and how to allocate emergency measures with corresponding emergency response capability. If rapid, rational, timely and effective emergency response measures could be taken in accordance with the evolution law of social unconventional emergencies, the incident control time and possible damages and losses would be substantially reduced. In order to realize the above goals, it's imperative to study the revolution law and response capability of social unconventional emergencies.

Compared with the traditional crises or disasters, human being lack in-depth scientific understanding for resource allocation and scheduling under those unconventional emergencies and in practice there is also a lack of corresponding emergency resource allocation and scheduling model. Therefore, traditional emergency management models cannot meet the needs of emergency management of unconventional events. The practice of emergency response for social unconventional events shows that it's particularly important how to control the emergency response plan at the earliest time according to the nature of events and extent of damage, and how to allocate emergency measures with corresponding emergency response capacity.

The research of this paper not only focuses on the evolution law and response capability of security precaution system in social unconventional emergencies with a combination of the latest achievements and approaches of management discipline and computer science in the field of safety precaution, but also discusses emergency resource allocation and scheduling model under non-conventional social emergencies and analyzes the model with examples. The remainder of this paper is organized as follows: In section 2, related work

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on evolution law and response capability of unconventional emergency is discussed. In section 3, we present evolution model of social unconventional emergency. In section 4, we discuss the response capability of security precaution system. In section 5, the description of the emergency resource allocation and scheduling model is made, at the same time, an example for case study is given. Finally, we draw the conclusion in section 6.

II. Related Work

A. *Domestic Researches*

In this respect, a small amount of literature deals with the genesis mechanism of certain specific public emergency, such as Feng Wenquan's research on the genesis mechanism of economic emergency, genesis of public safety and rural mass emergency, college emergency, and highway emergency. [1][2][3] Compared with emergency, there are much more literature about the evolution of disaster. Considering that some of public emergencies and disasters can be basically the same, the research on emergency evolution is to be introduced based on the current situation of research on disaster evolution. According to different discipline systems and different phases of evolution, research on disaster evolution can be classified as follows: according to discipline division, there are researches on disasters in the field of sociology and natural science, and the latter could be further divided according to different types of disasters. According to different stages, there are researches on disaster genesis and disaster diffusion. In the following part, the current situation of research on disaster genesis and disaster diffusion will be respectively explained based on discipline division.

Research of disaster in the field of sociology includes disaster management and relevant research. Research on disaster management mainly discusses disaster mitigation and precautionary management, and there is literature expounding the genesis of various types of disaster and their diffusion [4][5]. She Lian and others [6] made research on the genesis of road traffic disasters, railway traffic disasters, water transportation disasters, civil aviation transportation disasters and proposed the idea and methods of establishing traffic disaster precautionary system. There is literature in which the effects of secondary disasters on the whole society are introduced from the perspective of the impacts of disasters [7]. The genesis of disasters is explored from the perspective of balance between social and natural system. Some scholars analyzed the impacts of natural disasters on specific social systems, for example, there is literature elaborating the genesis, characteristics, prone positions and influential factors of chemistry enterprises' secondary disasters after earthquake and submitting comprehensive defensive measures [8]. Still, some literature offered the theoretical framework for an industrial production system to make risk analysis of secondary disasters. They adopted the method of fault tree analysis to explore how to find various disaster-causing factors, and provide reference for the implementation of safety management.

In other literature the impacts of disasters on national economy is analyzed from the perspective of disaster economics [9][10]. Literature in the field of domestic disaster sociology and disaster management shows that researches on disaster genesis have been carried out [11]. Wei Yiming and others discussed the complexity of disaster and proposed to use basic mathematical tools of complexity theory (fractal, chaos, neural networks and other nonlinear dynamics methods) to study and analyze the complex phenomenon of flood, establishing a Swarm-flood-based spatial and temporal evolution simulation platform, carrying out simulation case study of spatial and temporal evolution of flood, and obtaining certain law of spatial and temporal evolution of floods [12].

B. *Overseas Researches*

With regard to the evolution research of emergency, as early as 1975, based on their summary of the literature about disaster, Mileti and others proposed four phases of disaster life cycle [13], i.e. response, recovery, preparation and mitigation. After that, Park with others used the four stages and made research on the development process of the Chernobyl nuclear accident [14]. Based on the time series of disaster evolution, Stallings and Quarantelli studied the impacts before, during and after the disaster [15]. According to Thomas' systematic commentary on disaster, there is discussion about types and different stages of disaster in the past decade, but few of them involve the evolution and characteristics of public emergency. Typical evolution models of social emergency in foreign literature are summarized as follows:

(1). Turner's Model of Disaster Phases

On the basis of investigation on three disasters, Turner made description of disaster development according to the impact and consequences of disasters [16]. In his model, the evolution process is divided into seven phases, i.e. event starting point in theory, the incubation phase, rapid phase, outbreak phase, rescue and assistance phase, social adjustment phase. In his view, evolution process of disaster generally passes the above cycle, disaster mitigation and measures are different in each phase. While Turner did not give in-depth analysis of pre-disaster phase, simply took disaster genesis as the event starting point in theory. In addition, the division of disaster stages in this model is mainly based on the human community's different response measures to disaster.

(2). Turner's Model of Pre-disaster Phase

Since there is no analysis of disaster genesis in Turner's phase model, in 1992, Turner built a pre-disaster phase model . In his view, at the pre-disaster phase, the interaction and coupling of a variety of incentives eventually lead to the outbreak of large-scale accident or disaster. In this model, case study analysis and qualitative methods are adopted to explore the genesis mechanism of public emergency.

(3). Ibrahim-Razi's Model

Ibrahim-Razi model derived from the investigation report of seven disasters in Malaysia from 1968 to 2002, and it further divided the pre-disaster phase into eight phases [17]: 1) the error generated phase; 2) error accumulation phase; 3) Warning phase ; 4) rectification or correction stage; 5) unsafe state phase; 6) induced events appearance phase; 7) protection and defense phase; 8) disaster outbreak phase. The model is based on the interaction mechanism of various factors within the organizational system, aiming at avoiding the outbreak of incident through analysis of interaction of various factors in disaster incubation period. The model also describes the domino effect of independent or interrelated dangerous organizations.

(4). Emergency Evolution Model

In 1995, according to the development process of humanitarian emergencies, Burkholder and others put forward the three-stage emergency model [18]. The model divides emergency into three stages: acute emergency phase, late emergency phase and post-emergency phase. The model describes the state of different stages of emergency and they point out that different objectives must be set and different measures must be taken to quell an emergency according to stage characteristics of emergency.

(5). Crisis Phase Model

In 1986, Fink drew lessons from the disease development process and divided the crisis development into four phases [19]: stimulating phase, acute phase, delayed phase, and resolution phase. According to him, it’s most likely to prevent and intervene crises at the stimulating phase; crises at the acute phase are fast and highly destructive in characteristics; delayed phase refers to the stage where crises are alleviated and management personnel could carry out effective crisis management; and in resolution phase crises are completely resolved, which is the ultimate goal of crisis management.

In the area of emergency resource allocation, Toregas along with other people [20] first proposed location set covering model, the objective of which is to determine the required minimum number of emergency service facilities and to configure these emergency service facilities so that all the demand locations can be covered. Church and ReVelle made [21] the largest coverage model. In their model, they considered that because of the constraints of funding budget, it’s difficult to cover all the demand locations, therefore, the location of facility P is determined to enable the maximum value (population or other indicators) of covered demand locations. Hogan and ReVelle used the concept of alternate coverage [22] to modify the largest coverage model and put forward two alternative coverage models BACOP1 and BACOP2. Hakimi [23] first considered from the aspect of "efficiency" of service facility and proposed P-Median Model, whose aim is to choose P facilities to realize the minimum total weighted distance between demand locations and P service facility.

From the aspect of "fairness" of service facilities, Hakimi [24] raised P central issue, choosing P facilities to realize the minimum largest weighted distance between demand locations and service facilities. Cornuejols, Fisher and Nemhauser [25] conducted a detailed classification and specific analysis on uncapacitated facility location problem (UFLP). Tseng Kuo-hsiung from Taiwan University [26] studied the problems in the distribution of relief material and proposed the establishment of "emergency supplies distribution center" through reasonable siting, which could significantly improve the distribution efficiency of relief supplies and improve the responsiveness of the rescue.

Barbarosoglu 27] studied resource layout problems in Turkey earthquake. Karl F. Doerner [28] studied two regions of the port city of Galle in southwestern Sri Lanka, where the location and layout of school and other public security facilities take into account the risk of tsunami inundation. Chang [29] studied resource placement problems at different levels in the context of the floods in Taipei. Under the condition that the fire location is known and the city’s total amount of fire control resource is limited, Jia Chuan-Liang [30] established the fire control resource layout model during multi-stage process of extinguishing the fire. Sun Ying [31] gives mixed integer programming model in resource layout of highway emergency management. Jing Jia [32] studied the revised model of emergency medical services (EMS) facility location system on the occurrence multi-point large-scale emergency. Song Yuantao [33] established a limited ambulance location model with double covering standards.

In the area of emergency resource scheduling, Resource scheduling is defined as the follows: on the occurrence of unexpected events, based on the command and dispatch system's instructions, and the current demand for aid resources, corresponding departments identify the emergency service facility location and the volume of resources, constitute resource transportation routes and multi-stage schedule resources in accordance with changes of events.

Linet [34] and others studied the emergency logistics scheme at natural disasters, established resource scheduling model for various modes of transport and offered algorithms and numerical examples. AliHaghani [35] and others describes emergency resource transportation scheduling as time windows limited multi-object, multi-model network flow problem. The study assumes that the goods and vehicles can fully meet the needs, and the goal is to minimize transportation costs, and the author gives two kinds of solution method. FiedriCh [36] and others offer optimal planning model after earthquake: Under the condition of limited time, resource quantity and quality, quality of rescue could be improved through the efficient use of resources, achieving the smallest number of deaths and allocating and transporting resource to a number of disaster-stricken areas.

Konstaninos et al [37] studied road network incident response model based on the timely decision support system, with the goal to make the shortest response time. Jae Young hoi [38] studied how to allocate limited resources (such as ambulances and other emergency response vehicles) and transport the injured to hospital in the case of uncertainty of road network, aiming at the largest number of survivors. He Jianmin, Liu Chun-lin [39] discussed the multi-depot combinatorial optimization problem from a non-path angle and in two cases. They used fuzzy optimization method to examine the multi-depot vehicle scheduling problem in restricted period, and gave out a compromising scheme in meeting the conditions of the earliest starting time and the least number of rescue points. Dai Gengxin [40] and others studied emergency scheduling problem of multi-resource combination, and established multi-resource combination model; Based on the knowledge of correlation, Gao Shuping et al [41] studied multi-resource emergency systems scheduling and established a more realistic stochastic model.

In summary, foreign scholars' studies on evolution of public emergencies focus on the social-technical disasters and accidents areas, few studies involve natural disasters and emergency evolution. They generally divide incident evolution phases from the perspective of disaster sociology, security management, and international relationship and on the basis of human social systems, and take different measures based on specific phase characteristics of public emergency.

III. EVOLUTION MODEL OF SOCIAL UNCONVENTIONAL EMERGENCY

In order to study the evolution law of social unconventional emergency, we need an objective and scientific characterization and description of the whole evolution process of social unconventional emergency over time. Thus, we introduce the concept "concern degree of social unconventional emergency". Since the most direct manifestation of incidents from occurrence to disappearance is a series of phenomena over time, there exists inevitable link between incidents and phenomena. For anything, we can find some represented phenomena as description. Concern degree can be understood as those phenomena that best reflect the incident evolution.

Characteristics of concern degree is used to describe concern degree, and can describe concern degree from many aspects in accordance with actual situation, such as occurrence probability of concern degree, loss degree and panic degree resulting from concern degree, etc. Suppose the social unconventional emergency recorded as x, and e, p, t respectively express concern degree of social unconventional emergency, characteristics of concern degree, and time attributes, thus the mathematical expression for the evolution model is: x = f (e, p, t), where f expresses the mapping of concern degree of social unconventional emergency, characteristics of concern degree and time attributes to social unconventional emergency. By studying this model, we can have scientific understanding of evolution law of social unconventional emergency.

C. Trainning of Concern Degree

Concern degree can be understood as a series of phenomena that best reflect the evolution of incidents, therefore, we need to make observations and collect statistics about social unconventional emergency, and sample some phenomena that characterize social unconventional emergency. These phenomena are taken as training samples and training on samples are carried out with the use of evolution model of social unconventional emergency. Through data analysis, some specific concern degrees are obtained to make scientific and objective description of social unconventional emergency. The flow chart of concern degree training is shown in Fig.1:

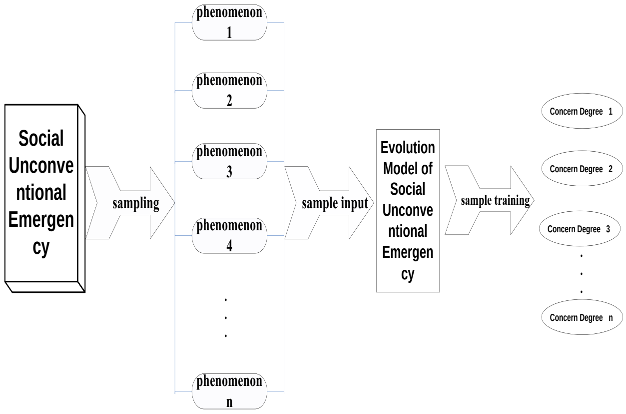

Fig.1: The flow chart of concern degree training

D. Correlation Research of Concern Degree

Because the mathematical model for evolution law of social unconventional emergency is x = f (e, p, t), where f indicates the concept of correlation, therefore, three types of correlation should be studied.

(1).The Correlation between Concern Degree and Social Unconventional Emergency

At this point correlation degree is used to describe the relationship between the occurrence of social unconventional emergency and its concern degree (more than one), i.e. the correlation degree of e and x. The graph description is shown in Fig.2:

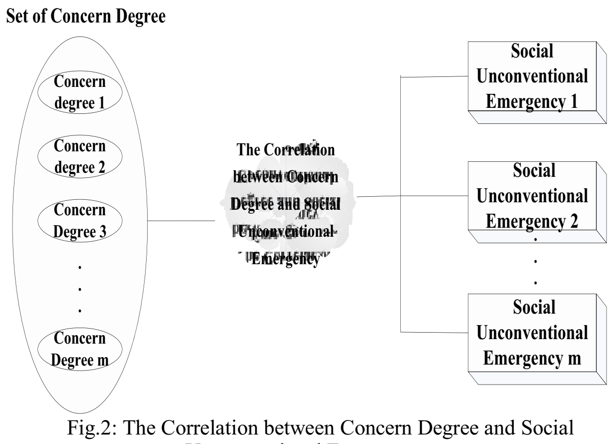

Fig.2: The Correlation between Concern Degree and Social Unconventional Emergency

(2). the Correlation between Concern Degree and Concern Degree

Mainly based on the fact that the occurrence of one concern degree may give rise to another, there may be some correlation between two concern degrees. The consideration of this correlation better describes the evolution law of incidents. And it's presented as the correlation degree between ei and ej. The description is shown in Fig.3:

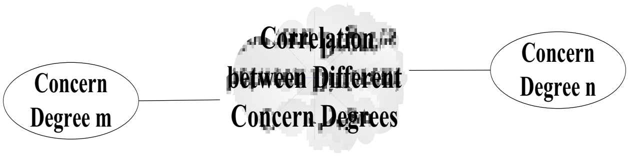

Fig.3: The Correlation between Concern Degree and Concern degree

(3). the Correlation of Same Concern Degree at Different Moments

For one same concern degree, the characteristics represented at different moments are different. However, there is still correlation among them. That is expressed as correlation degree between e (ti) and e (tj). The description is shown in Fig.4:

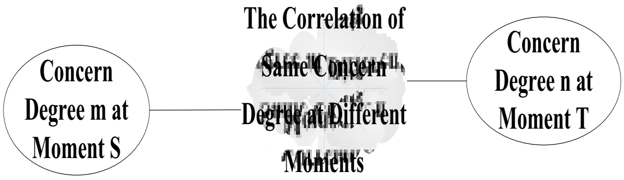

Fig.4: The Correlation of Same Concern Degree at Different Moments

The correlation degree of three types of correlation is obtained through analysis of concern degree and attributes values of concern degree, and then state characteristics of incidents are obtained through overlay calculation of all concern degrees according to certain correlation degree

IV. Response Capability of Security Precaution System

The security precaution system presented here refers to the concept of overall security precaution, which includes all elements of emergency preparation system and security precaution system as well. Response capability can be classified as static and dynamic response capability. The former refers to the assessment of response capabilities of security precaution system with the help of our evolution law model when incident X does not occur, and the latter refers to the assessment of response capabilities of security precaution system with the help of real-time data through dynamic access over time. Static response capability of security precaution system is our focus.

Suppose the discourse domain of social unconventional emergency is X={x1,x2,……xN}, where x1,x2,……xN respectively represent N types of social unconventional emergencies. Suppose social unconventional emergency x belongs to X. According to the above-mentioned evolution model of social unconventional emergency, the overall response capability of security precaution system for incident x (Suppose x at the moment t1 could be represented by conventional emergency e1,e2,e3, at the moment of t2 by conventional emergency e2,e3,e4) is obtained and recorded as F(x):

F (x) = u1 * m (t1) + u2 * m (t2) (1)

u1, u2, indicate weight, u1 + u2 = 1, and u1> u2, m (t1) <= m (t2)

m (t1) = s1 * y (e1) + s2 * y (e2) + s3 * y (e3) (2)

m (t2) = q1 * y (e2) + q2 * y (e3) + q3 * y (e4) (3)

Where s1, s2, s3, q1, q2, q3 indicate weights, y (e), indicate the response capability of security precaution system for conventional emergency.

V. The Establishment of Emergency Resource Allocation and Scheduling Model

A. Establishment of Emergency Resource Allocation Model

According to statistics of disaster emergency supplies from government departments over the years, the year's total amount of emergency demand is configured with the help of grey predication model. Map of research is as follows:

(1). establish the origin data sequence according to emergency supply sample data over the years:

$$x^{(0)} = [x^{(0)}(1), x^{(0)}(2), ...x^{(0)}(n)] \qquad (4)$$

(2). the preceding origin data sequence is processed for r-order accumulation, making the following data sequence:

$$x^{(l)} = [x^{(l)}(1), x^{(l)}(2), ...x^{(l)}(n)] \qquad (5)$$

Where: $x^{(l)}(k) = x^{(0)}(1) + x^{(0)}(2) + ... + x^{(0)}(k)$

$$x^{(l)}(1) = x^{(0)}(1)$$

(3).establish a whitening nonlinear differential equation of first order

$$\frac{dx^{(l)}}{dt} + ax^{(l)} = u \qquad (6)$$

(4). the value of a, u expressed in matrix form can be obtained through the application of least-squares method and maximum principle:

$$\hat{a} = \begin{bmatrix} a \\ u \end{bmatrix} = (B^T B)^{-1} B^T Y_N \qquad (7)$$

Where: $Y_N = [x^{(0)}(2), x^{(0)}(3), ...x^{(0)}(n)]$

$$B = \begin{bmatrix} -\frac{1}{2}[x^{(1)}(1) + x^{(1)}(2)], 1 \\ -\frac{1}{2}[x^{(1)}(2) + x^{(1)}(3)], 1 \\ .... \\ -\frac{1}{2}[x^{(1)}(n-1) + x^{(1)}(n), 1 \end{bmatrix}$$

After B is obtained, seek B^T and $(B^TB)^{-1}$

(5). seek the solution of whitening differential equations, namely the time corresponding function is as follows:

$$\hat{x}^{(1)}(t+1)=[x^{(0)}(1)-\frac{u}{a}]e^{-at}+\frac{u}{a} \quad (8)$$

Discrete response function is as follows:

$$\hat{x}^{(1)}(k+1)=[x^{(0)}(1)-\frac{u}{a}]e^{-at}+\frac{u}{a} \quad k=0,1,...n-1 \quad (9)$$

(6). A regressive for the generated model, the original sequence prediction results can be reverted

$$\hat{x}^{(0)}(k)=[x^{(1)}(k)-x^{(1)}(k-1)] \quad (10)$$

B. Establishment of Emergency Resource Scheduling Model

According to multi-objective-based single emergency location resource scheduling model, considering the uncertainty of resource demand in multi-stage emergency scheduling process, the corresponding model is established and simulated. Map of research is as follows:

Suppose there is one single emergency location (denoted as A), and the emergency response process requires n phases, the resource demand for phase j is (j=1,2….n), there are m(m>1) emergency rescuing locations, the total amount of emergency response supply offered by emergency rescuing location i at phase j to emergency location is (i=1,2⋯.m), the consumption of response capacity of emergency supplies is v (non - uniform),the demanded time for emergency supply to be delivered from rescuing location to emergency location is >0, suppose (The time needed from the same rescuing location to emergency location at every stage is the same). Considering the constraints of “how to make an emergency response the earliest time” and “the least number of rescuing locations” at every stage of emergency response process, a non-uniform multi-constraint multi-stage mathematical model is as follows:

$$\min\sum_{j=1}^{n} z_i^j, \min S_j \quad (11)$$

The earliest emergency response time forms a set $C_{s_j} \neq \phi$

$$\text{S.T} \quad z_i^j(z_i^j-1)=0 \ , \ \sum_{i=1}^{m} x_{ij} \geq x_j \ , \ \sum_{j=1}^{n} x_{ij} \geq \int_0^{t_j} f_j(t)dt$$

$$(i=1,2,….m; j=1,2,…..n)$$

Among them, binary decision variable z_i^j corresponds whether rescuing location i is involved in stage j, the value is {0, 1}. When rescuing location i is involved in the emergency response action of stage j, z_i^j =1, otherwise z_i^j =0. The consumption rate of emergency resource is v=f(t), $\int_0^{t_i} f_j(t)dt$ is the consumed resource amount at the moment of t_i in stage j of an emergency response. The constraint $\sum_{i=1}^{m} x_{ij} \geq x_j$ means the total amount of emergency resource offered to emergency location at stage j is greater than or equal to the total demand of resource at stage j.

C. Case Study

It is supposed that there are ten rescue points, one emergency point. It needs three resources. The reserve amount of resources in each rescue points is as follows in Fig.5:

Resource	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
X_1	9	2	3	8	3	2	3	6	12	2
X_2	6	4	4	5	5	6	11	2	3	6
X_3	4	5	2	3	3	8	1	2	3	10

Fig.5: The reserve amount of resources in each rescue points

The requirement of three kinds of resources in emergency point is (21, 19, 18) . The transportation time from each rescue points to emergency point are (2, 3, 3, 4, 6, 9, 10, 11, 14, 18). The total resource transportation is divided into four stages. x_{ij} are (5, 3, 1, 4, 1, 1, 2, 1, 1) . Resource consumption rate f(t)=2e^{-t}. So we get the best resource scheduling program based on the above model is as follows in Fig.6:

Resource	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
X_1	5	1	4	5	2	1	2	1	0	0
X_2	4	3	2	3	3	2	2	0	0	0
X_3	3	4	2	1	2	5	1	0	0	0

Fig.6: The best resource scheduling program

VI. CONCLUSION AND OUTLOOK

In this paper, through the establishment of the evolution model, scientific and objective description is made for social unconventional emergency, and the response capability of security precaution system is assessed through concern-degree-based assessment approach. The response capability values of security precaution system are provided at different concern degrees as decision references for the country’s efficient, orderly and scientific response to social unconventional emergency.

Unconventional social emergencies not only bring disasters to human life and living environment, but also cause damage to country and human. They also tend to cause a chain of reactions and inspire a lot of social problems, thus are likely to break the equilibrium of society and lead to national instability and social disharmony.

To solve the problem of emergency resource allocation and scheduling under unconventional social emergencies, in this paper, a model based on grey prediction is proposed in emergency resource allocation, which optimizes the year’s total amount of emergency resource in a comprehensive way. However, the model is only established through mathematical time and "the least number of rescuing locations" are solved. However, in the paper there is a limit in description and expression of changing events and process, and the mutual problems of "how to make an emergency response the earliest transformation of events and processes of multiple space time needs to be further explored.

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