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Random Decision and Simulation for the Situation Termination of Disaster Emergency Service

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Abstract: To determine the stopping time of disaster emergency, this study put forward the Markov chain's decision model of emergency situation termination at first time. The situation of emergency had two situations, including emergency tension situation and emergency stationary situation after the study analyzed the influence factors of emergency termination situations. Firstly, this study found out the maximum time by Markov decision model after emergency situation had gone into the stable phase and then the study established Markov chain's decision model of emergency situation termination, the optimal stop theory was used to solve the question of the emergency termination to find the most optimal termination time during the N. The Markov chain's model of emergency situation termination could accurately solve the question of the quantification decision of the end time of emergency situation and the calculation was simple. Markov model provided the theory support for emergency termination decision of the disaster service.

Key words: Emergency termination, Markova chain model, steady situation distribution, optimal stopping, situation probability, service science

INTRODUCTION

Termination of emergency condition, as the last step of emergency response mechanism, is crucial to the transition of emergency management and service from tension situation to steady situation and further to the ordinary situation, that severe secondary disaster and huge waste of properties might be caused if it stops too early or too late. After a disaster, the emergency decision-making organization shall collect relevant information promptly for an effective assessment of the time to terminate this emergency work, which is important to raising and distribution of emergency supplies, acceleration of disaster relief and lower emergency cost. Meanwhile, such assessment is used as the basis in decision making for the launch of post-disaster rehabilitation and reconstruction. According to the current practice of disaster relief, the termination time is determined mainly based on the past experience, that no sound foundation is available, which poses great risks to achieving the entire relief goal and increases the threat of secondary disaster. Therefore, it is required to go deep into the issue of the termination of emergency condition, which is not only essential for the correct termination of emergency process, but also important for high efficiency of disaster relief.

The issue concerned is covered in the study of emergency management mechanism and there have been many researches concerning the composition of emergency management mechanism (Shan *et al*., 2011; Han and Liu, 2006; Zhong, 2008; Corriveau, 2000; Fiedrich *et al*., 2000; Chen *et al*., 2007; Li *et al*., 2013) and the implementation of its single parts. The issue itself, however, is seldom involved. According to the existing literatures relevant, the major consideration is to design the optimal stopping mechanism based on single factor influencing the emergency condition. For example, based on secretary problem with finite scenarios, Chen and Wu (2010) presented a model based on Optimal stopping Theory aiming at the maximization of efficiency index and took termination mechanism as an important part of emergency management, which connects emergency response mechanism and reconstruction mechanism. This model is designed to find the optimal stopping time for the termination of emergency condition based on known stochastic efficiency, which makes little sense as the guidance for making decision in the progress of emergency relief.

In view of this, this study considers multiple factors that influence the termination of emergency condition, combines Markov decision-making process and Optimal Stopping Theory to build the termination model with finite

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scenarios and takes a simulation case to verify its feasibility and efficiency, in order to provide theoretical basis and technical support for the practice of emergency management, which is meaningful for higher efficiency of disaster relief and effective estimation of the total demand for and total capacity of emergency supplies.

MARKOV PROPERTY

Principle: In Markov process, the initial situation of a certain system is assumed as an input. If the moment n is regarded as the "current", the moment 0, 1, ..., n-1 as the "past" and the moment n+1 as the "future", Markov property indicates that when the "current" situation of a certain system is known, the conditional probability of any "future" situation of the system is independent to its "past" situations. The system will transfer among the potential situations with a certain probability distribution. That is, the "future" situation features stochasticity, which is similar to the efficiency variation of emergency system, resulted from the restriction of emergency capacity and other uncertain factors. Therefore, it is feasible to employ Markov process to deal with the issue concerned.

For the purpose of building termination model of emergency condition by Markov decision-making method, it is important to determine the time needed by each situation of the emergency system to come to steady situation. After that, the distribution probability of each measuring index is constant and the values of the situations obey exponential distribution (Liao *et al*., 2012). This is the first assumption in dealing with the issue concerned by Markov chain and its principle (Chen *et al*., 2004; Li *et al*., 2009; Mao *et al*., 2007) is: Let Ω be the population and P the probability measure of Ω and investigate the stochastic process with discrete time parameter and discrete situation space $X = \{X_n; n\in N^+\}$, $X_n \in E$, where time parameter set is $N^+ = \{0, 1, 2, \ldots\}$ and situation space $E = \{0, 1, 2, \ldots\}$. For $X = \{X_n;\ n\in N^+\}$ and for every $j\in E$ and $n\in N^+$, there is:

$$P\{X_{n+1} = j \mid X_0, X_1, \ldots, X_n\} = P\{X_{n+1} = j \mid X_n\} \quad (1)$$

Equation 1 is the Markov chain of stochastic process X, which is equivalent to: for any $n\in N^+$ and for any $i_0, i_1, \ldots, i_n, j\in E$, there is:

$$P\{X_{n+1} = j \mid X_0 = i_o, X_1 = i_1, \ldots, X_n = i_n\} = P\{X_{n+1} = j \mid X_n = i_n\} = p_{ij}^{(1)}(n) \quad (2)$$

Equation 2 describes the probability of the transition from situation i to situation j through one single step at moment n during the stochastic process X. Similarly, according to the Markov property of the stochastic process X, the probability for X to transfer from situation i to situation j through k steps at moment n can be expressed as:

$$p_{ij}^{(k)}(n) = P\{X_{n+k} = j \mid X_n = i\},\ i, j\in E, n \geq 0 \quad (3)$$

The probability properties of Eq. 2 and 3 are described by the initial probability distribution and the matrix of transition probability of homogeneous Markov chain. For the purpose of Eq. 2, the initial probability distribution of homogeneous Markov chain is assumed as:

$$P\{X_0 = i\} = p_i^0,\ p_i^0 \geq 0 \text{ and } \sum_{i\in E} p_i^0 = 1 \quad (4)$$

Then, for any $m\in N^+$ and $i_0, i_1, \ldots, i_m \in E$, there is:

$$P\{X_0 = i_0, X_1 = i_1, \ldots, X_m = i_m\} = p_{i_0}^{(0)} p_{i_0 i_1} p_{i_1 i_2} \cdots p_{i_{m-1} i_m} \quad (5)$$

Equation 5 shows that, once the initial distribution $\{p_i^{(0)}\}$ and the matrix of transition probability P are determined, the finite dimensional combined distribution of $X_0, X_1, \ldots, X_m$, $m\in N^+$ can be determined; meanwhile, the probability of transition through multiple steps can be determined according to the probability of transition and total probability theorem. If there is a limit to the transition of k steps, i.e.:

$$\lim_{k\to\infty} p_{ij}^k = c_j$$

where, c_j is a constant and the nonnegative sequence $c = (c_1, c_2, \ldots)$ is a stable distribution of $\{X_n\}$.

According to the characteristics of disasters and the stochasticity of the fluctuation of the indexes of emergency condition, the optimal termination time must be solved as a certain time or window before the entire emergency system is tending towards a steady situation, that it is not conductive to the maximization of the efficiency of emergency response when such termination is too early or too late. Such principle of Markov chain provides the theoretical method to solve the issue concerned. In discussing the termination of emergency condition, the first thing is to obtain the times, through which the entire emergency system reaches stable distribution by several steps (situations), then we can determine the optimal termination time before the time reaching steady situation based on Optimal Stopping theory.

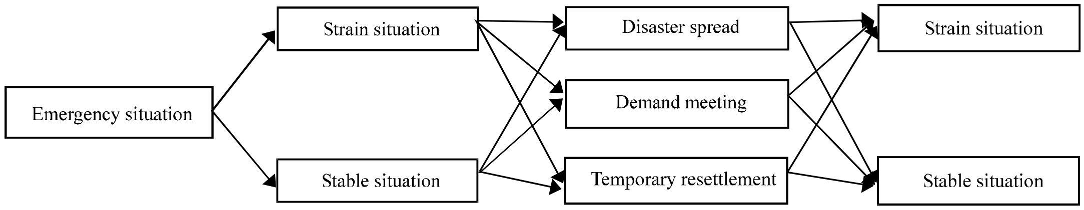

Fig. 1: Disaster emergency situation division

Measuring Indexes: Typically, in the early stage of disaster, a certain time is needed for emergency response and the information about disaster area is not available immediately, thus it is not possible to meet the demand in disaster area rapidly. In this stage, the emergency works is in a high-tension situation. With the launch of disaster relief, more and more information about disaster area is becoming available rapidly and the emergency capacity is getting improved, compared to the early stage of disaster, thus the demand in disaster area can be met fast. In another word, the emergency work comes to steady situation and finally termination situation. Therefore, the emergency condition can be divided into two finite situations: tension situation and steady situation, with the population of finite situation: E = {0, 1, 2}. For a comprehensive measurement of the entire process of emergency condition, the indexes must be selected highlighting the tasks and objectives of disaster relief, at the same time, they shall be able to be used throughout the entire process of situation transition, while relatively independent to each other. Therefore, the measuring indexes for emergency condition should be extracted from disaster control, demand satisfaction, temporal settling (including for the casualty), emergency cost, social impact factors and other aspects. Among these aspects, social impact factors, such as public panic, can last for a long time, which is difficult to quantify. Meanwhile, such panic is influenced by the level of disaster, efficiency of relief and other factors during the limited time of emergency; besides, the main manner to eliminate it is long-term self adjustment and psychological aids. Therefore, no social factor is included as the measuring index for emergency condition.

As the focus of emergency works is not on its economic efficiency, emergency cost is not included as a measuring index for emergency condition. To sum up, this study selects Disaster Spread, Demand Satisfaction and Temporal Settling as the measuring indexes for emergency condition Fig. 1.

For the calculation of probability of emergency condition's occurrence, Disaster spread is the factor that would cause continuing spread or expansion of the coverage or loss of disaster after its breaking out. Based on the preliminary statistical data, or referring to past cases, two ranks (tension situation and steady situation) might be defined in terms of the occurrence of disaster in unit time according to certain criterion and the frequency of each rank can be counted separately. Take flood for example, the two ranks might be defined in terms of the coverage expansion in unit time and the frequency counted for each rank could be regarded as the probability of transition (0, if there is no occurrence). In the same way, the two ranks for epidemics might be defined in terms of the variation of number of infections and earthquake in terms of the numbers of aftershock. Demand Satisfaction is the supply-to-demand ratio of emergency supplies and the calculation of probability of each situation is similar to that of Disaster spread. Temporal settling concerns the ratio of population settled vs. population to be settled. In brief, two ranks are defined for different situations in terms of such ratio and the frequency counted for each rank is regarded as the probability of transition.

MARKOV DECISION-MAKING PROGRESS

Basic assumptions: The vector of Markov chain of emergency condition is assumed as $\{\xi_n^1, \xi_n^2, \xi_n^3\}$, where ξ_n^1 is the Markov chain of Disaster Spread, ξ_n^2 the Markov chain of Demand Satisfaction and ξ_n^3 the Markov chain of Temporal settling. If the first-order probability of transition P (n, 1) is independent to n, the vector of Markov chain $\{\xi_n^1, \xi_n^2, \xi_n^3\}$ is time-homogeneous Markov chain and the first-order probability of transition would be marked as P (1). That is, for any positive integer, there is P (n,1) $=P_{ij\,(1),}$, I,j = 1, 2.

The probability of tension situation is assumed as P (X = 1) and that of steady situation as P (X = 2);

For disaster spread, the probability elements of one-step transition between the two situations are ε_{11}, 1-ε_{11} and ϵ_{21}, 1-ϵ_{21}, for Demand Satisfaction are η_{11}, 1-η_{11} and η_{21}, 1-η_{21}; for Temporal Settling are μ_{11}, 1-… and μ_{21}, 1-μ_{21}.

Optimal stopping time decision: Determining the maximum planning stopping time: Based on the assumptions above, there are two situations and three measuring indexes for emergency system. For Disaster Spread, Demand Satisfaction and Temporal Settling, the probability matrices of their transition between the two situations are assumed as P_{ij}, P_{ij}^{1} and P_{ij}^{2}, respectively and the vector matrix of k-step transition is:

$$P_{ij}(k)=\begin{bmatrix}(P_{11}(k) & P_{12}(k)) & (P_{11}^{1}(k) & P_{12}^{1}(k)) & (P_{11}^{2}(k) & P_{12}^{2}(k))\\ (P_{21}(k) & P_{22}(k)) & (P_{21}^{1}(k) & P_{22}^{1}(k)) & (P_{21}^{2}(k) & P_{22}^{1}(k))\end{bmatrix} \quad (6)$$

Where:

$$P_{ij}^{s}(k)=P\left\{X_{m+k}^{s}=j_{m+k}^{s}\mid X_{m}^{s}=i_{m}^{s}\right\},\ 0\le P_{ij}^{s}(k)\le 1$$

and:

$$(i,j=1,2;s=1,2,3;k=1,2,\ldots),\ \sum_{j=1}^{3}P_{ij}^{s}(k)=1$$

The initial situation of emergency system is assumed as B and the condition vector after a transition through n unit intervals is C. According to C-K (Chapman-Kolmogorov) Eq. 9, there is:

$$P(X_n)=P(X_0)P(n)=P(X_0)[P(1)]^{n} \quad (7)$$

Therefore, the probability distribution of emergency condition after n stages can be calculated based on the initial situation and the probability of one-step transition. Based on the conditions given above, it is possible to get the distribution function of P (X_n):

$$\begin{aligned}
&P(X=1)=P(X_n=1,X_{n-1}=1)+P(X_n=1,X_{n-1}=2)\\
&=P(X_n=1\mid X_{n-1}=1)P(X_{n-1}=1)\\
&+P(X_n=1\mid X_{n-1}=2)P(X_{n-1}=2)\\
&=[P_{11}P(X_{n-1}^{1}=1)\cdot P_{11}^{1}P(X_{n-1}^{2}=1)\cdot P_{11}^{2}P(X_{n-1}^{3}=1)]\\
&+[P_{11}P(X_{n-1}^{1}=2)\cdot P_{11}^{1}P(X_{n-1}^{2}=2)\cdot P_{11}^{2}P(X_{n-1}^{3}=2)]\\
&=\varepsilon_{11}.\eta_{11}.\mu_{11}P(X_{n-1}^{1}=1).P(X_{n-1}^{2}=1).P(X_{n-1}^{3}=1)\\
&+\varepsilon_{21}.\eta_{21}.\mu_{21}\{[1-P(X_{n-1}^{1}=1)].[1-P(X_{n-1}^{2}=1)]\\
&\cdot[1-P(X_{n-1}^{3}=1)]\}\\
&=\{[(\varepsilon_{11}-\varepsilon_{21})P(X_{n-1}^{1}=1)+\varepsilon_{21}]\cdot[(\eta_{11}-\eta_{21})P(X_{n-1}^{2}=1)+\eta_{21}]\\
&[(\mu_{11}-\mu_{21})P(X_{n-1}^{3}=1)+\mu_{21}]\}\\
&=\{(\varepsilon_{11}-\varepsilon_{21})^{2}P(X_{n-2}^{1}=1)+\varepsilon_{21}[1+(\varepsilon_{11}-\varepsilon_{21})]\}\\
&\{(\eta_{11}-\eta_{21})^{2}P(X_{n-2}^{2}=1)+\eta_{21}[1+(\eta_{11}-\eta_{21})]\}\\
&\{(\mu_{11}-\mu_{21})^{2}P(X_{n-2}^{3}=1)+\mu_{21}[1+(\mu_{11}-\mu_{21})]\}\\
&\qquad\qquad\ldots\ldots\ldots\ldots\\
&=\{[(P(X_0^{1}=1)-\frac{\varepsilon_{21}}{\varepsilon_{11}+\varepsilon_{21}})\cdot(\varepsilon_{11}-\varepsilon_{21})^{n}]+\frac{\varepsilon_{21}}{\varepsilon_{11}+\varepsilon_{21}}\}\\
&\{[(P(X_0^{2}=1)-\frac{\eta_{21}}{\eta_{11}+\eta_{21}})\cdot(\eta_{11}-\eta_{21})^{n}]+\frac{\eta_{21}}{\eta_{11}+\eta_{21}}\}\\
&\{[(P(X_0^{3}=1)-\frac{\mu_{21}}{\mu_{11}+\mu_{21}})\cdot(\mu_{11}-\mu_{21})^{n}]+\frac{\mu_{21}}{\mu_{11}+\mu_{21}}\}
\end{aligned} \quad (8)$$

In a similar way:

$$\begin{aligned}
&P(X_n=2)\\
&=\{[P(X_0^{1}=2)-(1\text{-}\varepsilon_{11})]\cdot(\varepsilon_{11}-\varepsilon_{21})^{n}+(1\text{-}\varepsilon_{11})\}\\
&\{[P(X_0^{2}=2)-(1\text{-}\eta_{11})]\cdot(\eta_{11}-\eta_{21})^{n}+(1\text{-}\eta_{11})\}\\
&\{[P(X_0^{3}=2)-(1\text{-}\mu_{11})]\cdot(\mu_{11}-\mu_{21})^{n}+(1\text{-}\mu_{11})\}
\end{aligned} \quad (9)$$

In case of a major disaster, the probability that the emergency control center launches emergency relief is 100% and the probability distribution of the initial situation of emergency condition can be assumed as:

$$P(X_0)=[(1\quad 1\quad 1)\quad (0\quad 0\quad 0)] \quad (10)$$

Where:

$$\begin{aligned}
&P(X_n)=[P(X_n=1),P(X_n=2)]\\
&=\{[\frac{\varepsilon_{11}}{\varepsilon_{11}+\varepsilon_{21}}\cdot(\varepsilon_{11}-\varepsilon_{21})^{n}+\frac{\varepsilon_{21}}{\varepsilon_{11}+\varepsilon_{21}}]\\
&[\frac{\eta_{11}}{\eta_{11}+\eta_{21}}\cdot(\eta_{11}-\eta_{21})^{n}+\frac{\eta_{21}}{\eta_{11}+\eta_{21}}]\\
&[\frac{\mu_{11}}{\mu_{11}+\mu_{21}}\cdot(\mu_{11}-\mu_{21})^{n}+\frac{\mu_{21}}{\mu_{11}+\mu_{21}}]\\
&[(\varepsilon_{11}\text{-}1)\cdot(\varepsilon_{11}-\varepsilon_{21})^{n}+(1\text{-}\varepsilon_{11})][(\eta_{11}\text{-}1)\cdot(\eta_{11}-\eta_{21})^{n}+(1\text{-}\eta_{11})]\cdot\\
&[(\mu_{11}\text{-}1)\cdot(\mu_{11}-\mu_{21})^{n}+(1\text{-}\mu_{11})]\}
\end{aligned} \quad (11)$$

Equation 11 is the probability vector of emergency condition when the stochastic process X has been through n finite unit times; no matter the initial situation of emergency condition is 1 or 2. After the probability transition through several finite unit times, the probability that the emergency condition equals to 1 or 2 is tending to steady situation and the probability of such steady situation is independent to the initial situation. The probability of steady situation is assumed to be π and when the emergency system comes to steady situation, the condition A is true. That is to say, the probability that the emergency system comes to steady situation after several unit periods is π and the total time for it to come to π, N (where N is the number of days, the product of n, the total periods through which the emergency system comes to steady situation and the number of days of each period), is the maximum time for the termination of emergency condition. In another word, the probability of steady situation when all measuring indexes come to steady situation is:

$$\lim_{n\to\infty}P(X_1=2)=\lim_{n\to\infty}[(\varepsilon_{11}\text{-}1)\cdot(\varepsilon_{11}-\varepsilon_{21})^{n}+(1\text{-}\varepsilon_{11})] \quad (12)$$

$$\lim_{n\to\infty}P(X_2=2)=\lim_{n\to\infty}[(\eta_{11}\text{-}1)\cdot(\eta_{11}-\eta_{21})^{n}+(1\text{-}\eta_{11})] \quad (13)$$

$$\lim_{n\to\infty}P(X_3=2)=\lim_{n\to\infty}[(\mu_{11}\text{-}1)\cdot(\mu_{11}-\mu_{21})^{n}+(1\text{-}\mu_{11})] \quad (14)$$

The condition vector when the entire emergency system comes to steady situation is:

$$\begin{aligned}\lim_{n\to\infty}P(X_n) = \lim_{n\to\infty}\{&[\frac{\varepsilon_{11}}{\varepsilon_{11}+\varepsilon_{21}}\cdot(\varepsilon_{11}-\varepsilon_{21})^n+\frac{\varepsilon_{21}}{\varepsilon_{11}+\varepsilon_{21}}]\\ &+[\frac{\eta_{11}}{\eta_{11}+\eta_{21}}\cdot(\eta_{11}-\eta_{21})^n+\frac{\eta_{21}}{\eta_{11}+\eta_{21}}]\\ &+[\frac{\mu_{11}}{\mu_{11}+\mu_{21}}\cdot(\mu_{11}-\mu_{21})^n+\frac{\mu_{21}}{\mu_{11}+\mu_{21}}],\\ &[(\varepsilon_{11}\text{-}1)\cdot(\varepsilon_{11}-\varepsilon_{21})^n+(1\text{-}\varepsilon_{11})]\\ &+[(\eta_{11}\text{-}1)\cdot(\eta_{11}-\eta_{21})^n+(1\text{-}\eta_{11})]\\ &+[(\mu_{11}\text{-}1)\cdot(\mu_{11}-\mu_{21})^n+(1\text{-}\mu_{11})]\}=\pi\end{aligned} \quad (15)$$

According to the characteristics of emergency work, when emergency condition comes to steady distribution, it is the time to terminate emergency condition, but not the optimal termination time. As it is impossible to restore the original condition after a disaster, social disorder and damage to human life and people's property are the inevitable results of disaster, so that the primary objective of each emergency relief is to cure the injured with all efforts, to satisfy the demand in disaster area as possible, to save the trapped, to arrange temporal settling and to take pretentious actions against secondary disaster, which calls for a huge amount of time, especially to satisfy the demand in disaster area as possible. Therefore, when the emergency condition comes to steady situation, it means that the emergency work in disaster area comes to ordinary situation, which means the termination of emergency condition; otherwise, it would be still in the relative tension situation. Therefore, the time when the emergency system comes to steady situation can be considered as the maximum planning stopping time, N, while the optimal stopping time of emergency condition is included in N.

Determining the optimal stopping time: For decision making of termination of emergency condition, the first goal is to find the total time needed by the emergency system to come to steady situation, N and the second goal is to determine the optimal stopping time before N, for maximum efficiency of emergency work, to provide the basis for decision making in estimating the demand for emergency supplies and launching the rehabilitation and reconstruction in disaster area. The issue of optimal stopping time of emergency condition is a typical issue of stochastic decision, which focuses on choosing a time or window in (0, N) as the optimal stopping time of emergency work. Only when such optimal stopping time is chosen can maximum time efficiency and minimum damage of disaster be available. With the value of N above, the next step is to decide the optimal stopping time of emergency condition within (0, N).

Basic assumptions on the issue of optimal stopping (Jin, 1995; Lorenzen, 1981; Yi, 1998).

Assuming that (Ω, F, P) is a complete probability space, $(F_n)_1^\infty$ is a row of increasing sub-σ algebra of F and for ∀n, there is $F_n \subseteq F_{n+1}$. For emergency work, Ω can be used to express the entire set of emergency condition, 1-ϵ_{11} the set of all events, P the measure of the probability of each event in f, then P (Ω) = 1.

Assuming a row of stochastic variables $(X_n)_{n=1}^\infty$, called Reward Function Sequence. For each n, X_n is F_n-measurable, marked as $X_n \in F_n$, then $\{X_n, F_n\}_{n=1}^\infty$ is called a stochastic sequence. When the value of stochastic variable {1, 2, ..., +∞} is 1-η_{11}, it is called the stopping time. At that time, if ∀n, {ω: t = n}∈F_n and P (t<∞) = 1, t is called stopping criterion. The entire set of stopping time is marked as $\bar{H}$ and the entire set of stopping criteria is marked as H.

Usually, we can observe the stochastic variables $y_1, y_2, \ldots, y_n$ in sequence and the reward function sequence X_n is corresponding to $y_1, y_2, \ldots, y_n$ and is known.

For the issue of optimal stopping of emergency condition, $(X_n)_{n=1}^\infty$ can be defined as the emergency reward sequence X_n (also called the emergency efficiency sequence) composed by the values of emergency efficiency of n days before each point to decide stopping in N (n≤N) days and each X_n is a sub-σ algebra of an increasing sequence of 1-ε_{21} from the maximum to the minimum, where each 1-ε_{21} is an increasing set of sub-events from 1 to +∞ and each X_n is corresponding to each 1-ε_{21} and measurable. There is at least one moment t that this condition is true, which composes the set of optimal stopping time.

Based on the assumptions above, it can be concluded that, for the optimal decision on the termination of emergency condition, the first step is to decide the measuring indexes of reward sequence and to determine the optimal decision criterion; the second step is to determine the stopping criterion and algorithm for each optimal criterion and the final step is to make decision for the optimal stopping time of emergency condition.

Proposition of measuring indexes of emergency efficiency and optimal criteria: Aiming at the maximum relief efficiency, the measuring indexes of emergency efficiency are chosen not only to represent the key factors influencing the emergency condition, but also to take account of those indexes influencing the maximum emergency efficiency. At the same time, it should be convenient to quantify these indexes. Generally speaking, time and cost are the key factors that influence the

Table 1: Measuring indexes of optimal stopping decision-making for emergency work

Condition index	Description	Calculation	Conversion
M_t	The time taken for emergency supplies from the submission of demand plans to actual distribution in disaster area	M_t= The total time needed for the distribution of each batch of emergency supplies/The number of demand calls	$M = 1/M_t$
C	The cost of emergency supplies and associated transportation cost everyday	C= The cost of emergency supplies everyday+Associated transportation cost	Q = 1/C

emergency efficiency. So far as the focus of emergency works is not on its economic efficiency, it is necessary to take the cost of emergency work into account as the time efficiency has priority. This is one of the important directions of emergency management research in the future.

Assuming that emergency supplies are provided everyday during emergency works, emergency cost is incurred everyday correspondingly. The index of time efficiency of emergency work focuses on the timeliness of emergency supplies, which means that the emergency system can meet the demand quickly and efficiently once there is any demand for emergency supplies. This is one of the decisive indexes to ensure the smooth performance of emergency works and one of its measuring indexes is the mean time of demand satisfaction (M_t), that less time needed for demand satisfaction means higher time efficiency. The index of cost efficiency of emergency works is composed of the cost of emergency supplies and the associated transportation cost, which is calculated as the total of expenses and cost everyday. Therefore, the emergency cost (C) is also a key measuring index (Table 1), that lower cost means higher cost efficiency. As M_t and C are relatively independent indexes during the entire process of emergency work, it is impossible to use one combined index to take account of both and the only solution is to make decisions separately based on the optimal stopping criterion. For convenience, the method of determining optimal stopping by index M_t will be introduced as an example hereunder. For the purpose of making final decision, the solution is to choose the later of the two times determined separately by the two indexes as the optimal stopping time, in that the emergency condition shall be terminated only when both of the two indexes come to the optimal value, otherwise the optimal emergency efficiency is not available.

Let M (1), M (2), ..., M(N) be the values of M for N days. This is a decreasing sequence with all the elements ranked by their absolute values, in which M(1) is the greatest and M (N) the lowest and which is available only when the number of days comes to N, but not during making stochastic decisions. Only the values of M in the past n days are available for such ranking, resulting in a relative rank for making decision each time, which means that only a stochastic arrangement of 1, 2, ..., N is available for each stochastic decision; therefore, the goal of stochastic decision is to find the greatest probability with higher efficiency and higher rank. If the reward functions for more than two days in a row are the same, the corresponding values of M for these days could be ranked by the values of N. If one of these days is the optimal stopping time, any day in such row can be chosen when making decision, which is quite impossible in practice, as there are so many uncertain factors in emergency works that the mean time to meet the demand for emergency supplies is quite different everyday. Then, the issue of the optimal stopping time for the termination of emergency condition turns to solving the two standards below:

Standard 1: The probability that the time with greatest M is chosen as the termination time shall be the highest;

Standard 2: The time with the rank of M in the top of the possible arrangement shall be chosen as the termination time of emergency condition.

Formation of the stopping criteria for the two standards (Che and Jin, 1995; Frank and Samuels, 1980).

Let $\Omega = \{\alpha_1, \alpha_2,..., \alpha_N\}$, where $(\alpha_1, \alpha_2,..., \alpha_N)$ is an arrangement of (1, 2, ..., N); $y_{n} = (\alpha_1, \alpha_2,..., \alpha_n)$, where the relative rank of α_n is the number of elements less than α_n in y_n. Assuming $F_{n = \sigma (y1,\, y2...,\, yn)}$, then, For Standard 1, take the reward sequence:

$$\bar{X}_n = \begin{cases} 1, & a_n = 1 \\ 0, & a_n \neq 1 \end{cases} \tag{16}$$

but it does not meet the requirement that there shall be a measurable F_n. Let:

$$X_n = P(a_n = 1 \mid F_n), n = 1, 2, ..., N \tag{17}$$

then , for any stopping criterion t:

$$EX_n = \sum_{n=1}^{N} \int_{[t=n]} X_n = \sum_{n=1}^{N} \int_{[t=n]} P(a_n = 1 \mid F_n) = P(a_t = 1) \tag{18}$$

where, P (α_t = 1) represents the probability that the value of M ranks the first in the arrangement, i.e. the probability that the value of M is the greatest, when stopping criterion t is chosen. Then, the optimal criterion for optimal stopping of $\{X_n, F_n\}$ should be:

$$L = \inf\{n \geq r^* : y_n = 1\} \tag{19}$$

Where:

$$r^* = \inf\left\{r \geq 1: \frac{1}{r} + \frac{1}{r+1} + ... + \frac{1}{N-1} \leq 1\right\} \quad (20)$$

The lowest r that meets this condition is the value of r* and the time t corresponding to the greatest M after r* obeying Eq. 19 is the optimal termination time of emergency condition. For the convenience of calculation, r* can be obtained by calculating the limit of Eq. 19. Based on Eq. 20:

$$\sum_{d=r^*}^{N-1} \frac{1}{d} \leq 1 < \sum_{d=r^*-1}^{N-1} \frac{1}{d} \quad (21)$$

Then:

$$\int_{r^*}^{N} \frac{1}{y} dy = \sum_{d=r^*}^{N-1} \int_{d}^{d+1} dy \leq 1 < \int_{r^*-1}^{N-1} \frac{1}{y} dy \quad (22)$$

Therefore:

$$\lim_{N\to\infty} \ln \frac{N}{r^*} = 1$$

i.e.:

$$\lim_{N\to\infty} \frac{r^*}{N} = \frac{1}{e} \quad (23)$$

According to Eq. 23, when the value of N is known, the value of r* can be calculated directly and it is not necessary to take the values in sequence within (0, N) and substitute into Eq. 20 to obtain r*.

For standard 2, take the reward sequence:

$$X_n = -\frac{N+1}{n+1} y_n \quad (24)$$

The optimal criterion is:

$$W = \inf\{n \geq 1: y_n \leq W_n\} \quad (25)$$

Where:

$$w_n = [-\frac{n+1}{N+1} \bullet V_{n+1}], n = N-1, N-2, ..., 1, w_n = 0$$

[•] representative integer arithmetic:

$$V_N = -\frac{N+1}{2} \quad (26)$$

$$V_n = -E(\frac{n+1}{N+1} y_n \wedge (-V_{n+1})] \quad (27)$$

where, $1 \leq n \leq N-1$. Here a/\b is min (a, b),Now meeting time points t_n of rules of W is the optimal time of emergency termination.

Justifying:

$$V_N = EX_N = -Ey_N = -\frac{N+1}{2}$$

Here, y_n sequence is independent of each other.

Now using backward induction testifies that the optimal rules W = inf $\{n \geq 1: y_n \leq W_n\}$ is established. $\gamma_n = X_n \wedge E\gamma_{n+1}$ $E\gamma$, n = 1, 2, ..., N-1.

Presuming:

$$W_n = -[\frac{n+1}{N+1} V_{n+1}], W_N = 0, n = 1, 2, ..., N-1$$

i.e.:

$$V_n = -E(\frac{n+1}{N+1} y_n \wedge (-V_{n+1})] = -\frac{1}{n} \sum_{j=1}^{n} \left\{\frac{N+1}{n+1} j \wedge (-V_{n+1})\right\}$$
$$= -\frac{1}{n} \cdot \frac{N+1}{n+1} \sum_{j=1}^{n} j \wedge [-\frac{n+1}{N+1} \cdot V_{n+1}]$$
$$= -\frac{1}{n} \left\{\frac{N+1}{n+1} (1+2+...+W_n + (n-W_n)(-V_{n+1})\right\}$$

So, The optimal rule:

$$\sigma_1^N = \inf\{n \geq 1: X_n = \gamma_n\}$$
$$= \inf\left\{n \geq 1: \frac{N+1}{n+1} y_n \leq -V_{n+1}\right\}$$
$$= \inf\{n \geq 1: y_n \leq W_n\} = W_n$$

is established.

According to the above, we can design the algorithm of standard 2:

$$V_N = -\frac{N+1}{2}$$
$$n = N-1$$
$$W_n = -[\frac{n+1}{N+1} V_{n+1}], n = N-1, N-2, ..., 1$$
$$V_n = -\frac{1}{n} \left\{\frac{N+1}{n+1} (1+2+...+W_n + (n-W_n)(-V_{n+1})\right\}$$
$$t_n = \mathrm{int}(-\frac{n+1}{N+1} V_{n+1})$$
$$n = N-2$$

Among the outputs, the times that correspond to the condition t_n = 1 are the optimal times, which form a window, marked as (a, b).

Decision making for termination of emergency condition: For the purpose of decision making for termination of emergency condition, the optimal criteria for the two standards above can be employed separately or in combination. When Standard 1 is employed independently, it can be known immediately that the termination shall not be performed before int [r*] days when the value of r* is determined and it could be reasonable to terminate the emergency condition at the time t corresponding to the first time when the greatest time efficiency M occurs after int [r*]. The exact value of such t is only known after all is done, which is only meaningful for afterward assessment of emergency work, but meaningless for predicting the demand for emergency supplies, or for directing the comprehensive arrangement during the middle to late phase of disaster. Therefore, when the values of N and r* are known, the window to make decision for the termination time of emergency condition is narrowed down greatly and it is possible to perform case verification to estimate the time when the greatest M appears for the first time after int [r*]. Alternatively, the intersection (int [r*], N) ∩ (a, b) can be taken as the window, marked as (c, d) and the average of c, d might be taken as the optimal termination time.

Similarly, the optimal stopping time based on cost efficiency can be decided by the method above. The termination times determined by the two indexes separately are not always the same and the emergency condition shall be terminated only when both indexes show the optimal stopping condition. Generally, the optimal stopping time chosen based on the index of time efficiency prevails, according to the characteristics of emergency work.

CASE STIMULATION AND ANALYSIS

Taking some hard-hit areas in “5•12” Wenchuan Earthquake in 2008 as examples. The case stimulation is divided into two stages. Stage 1: Employing Markov chain model to find the latest termination time N, when the emergency condition comes to steady situation. For the initial stage, each 5 days is defined as one unit time. For Disaster Spread, the number of after-shocks during 13th, May to 17th, May is counted to obtain the stimulation data (Table 2) and the influences of different seismic intensities listed in Chinese Seismic Intensity Scale (1980) are referred to, where Tension Situation is defined when there are two earthquakes higher than Magnitude 5 or one earthquake higher than Magnitude 6 in a day, otherwise Steady Situation. For Demand Satisfaction, the supply-to-demand ratio of emergency supplies in initial stage is counted and medical supplies, which is considered as the most significant material influencing the emergency condition, is used as stimulation data, where Tension situation is defined when the supply-to-demand ratio is lower than 75% and Steady Situation when higher than 75%. This definition is reasonable and see Table 3 for the stimulation data. For temporal settling, the ratio of population settled (including the victims placed) vs. population to be settled in initial stage is counted, where Tension situation is defined when this ratio is lower than 84% and Steady situation when higher than 84%. See Table 4 for the stimulation data. For the purpose of this stage, it is only required to solve according to the optimal termination criteria of the two standards based on the value of $_N$ and the optimal termination time is to be solved in Stage 2:

Table 2: Aftershocks statistics in Wenchuan earthquake on May 13-17

Date	Frequency: Level 6.0 and above	Level 5.0~5.9	Level 4.0~4.9
On 13, May	1	5	41
On 14, May	0	2	16
On 15, May	0	1	10
On 16, May	0	1	10
On 17, May	0	2	11

Table 3: Initial stage of medical material supply and demand in Wenchuan earthquake

Date (May)	Medicine/unit: Demand planning	Actual deployment	Medical equipment /unit: Demand planning	Actual deployment	Disinfect supplies /t: Demand planning	Actual deployment
13	47308.97	2880.00	5.39	4.00		
14	2397.80	1.20	554.72	0.00	0.01	0.00
15	4403.31	4360.00	19340.67	183.00	11.81	3.10
16	7184.87	4040.90	4955.20	2754.80	14.18	9.10
17	15565.27	13903.09	4134.30	4134.30	173.87	115.52

Table 4: Initial stage of temporary placement in Wenchuan earthquake (13-17)

Planning times of temporary placement	Expectations number of temporary placement at a time/million	Actual number of temporary placement at a time/million
1	112	87.34
2	78	71.12
3	123	103.33
4	118	101.12
5	132	89.23
6	147	98.56
7	120	77.05

- **Stage 1:** The random distribution of steady situation of emergency condition

According to the data in Table 2, 3 and 4, the frequency of each index in initial stage is calculated, resulting to the vector of the probability matrix of one-step transition of emergency condition:

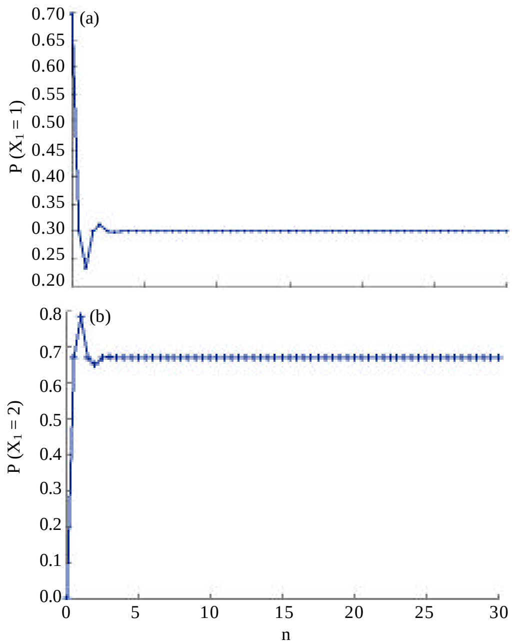

Fig. 2(a-b): Steady distribution of disaster spread

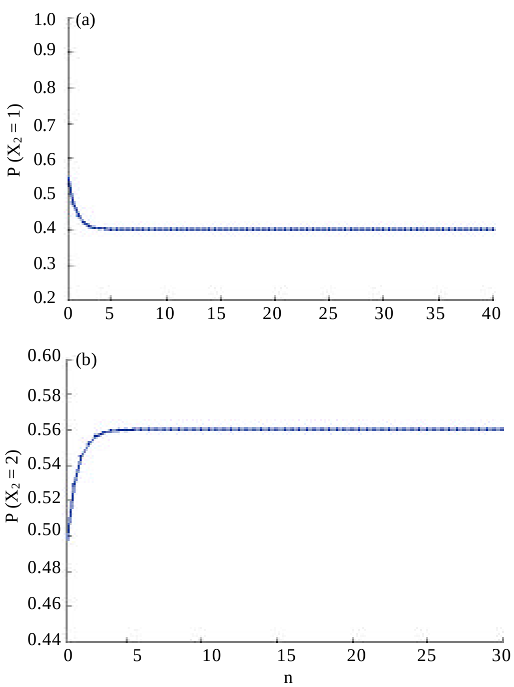

Fig. 3(a-b): Steady distribution of demand satisfaction of emergency supplies

$$P_{ij}(1)=\begin{bmatrix}(0.33 & 0.67) & (0.75 & 0.25) & (0.5 & 0.5)\\ (0.5 & 0.5) & (0.5 & 0.5) & (0.33 & 0.67)\end{bmatrix}$$

Then:

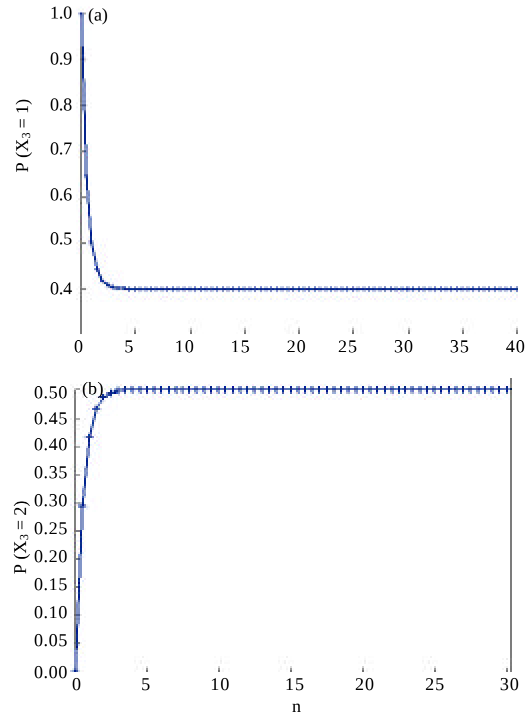

Fig. 4: Steady distribution of temporal settling

$$\varepsilon_{11}=0.33, 1\text{-}\varepsilon_{11}=0.67, \varepsilon_{21}=0.5, 1\text{-}\varepsilon_{21}=0.5;$$
$$\eta_{11}=0.75, 1\text{-}\eta_{11}=0.25, \eta_{21}=0.5, 1\text{-}\eta_{21}=0.5;$$
$$\mu_{11}=0.5, 1\text{-}\mu_{11}=0.5, \mu_{21}=0.33, 1\text{-}\mu_{21}=0.67$$

Based on Eq. 12-14 above, the stimulation graph of the transition of each measuring index can be obtained (Fig. 2-4).

According to Fig. 2-4, when Disaster Spread comes to steady distribution, $P(X_1 = 1) = 0.33$, $P(X_1 = 2) = 0.67$, before which there was a transition through 11 unit periods (i.e., 55 days); when Demand Satisfaction comes to steady distribution, $P(X_2 = 1) = 0.44$, $P(X_2 = 2) = 0.56$, before which there was a transition through 13 unit periods (i.e., 65 days) and when Temporal Settling comes to steady situation, $P(X_3 = 1) = 0.46$, $P(X_3 = 2) = 0.54$, before which there was a transition through 11 unit periods (i.e., 55 days). Among the three indexes, Demand Satisfaction calls for the longest time to come to steady situation; therefore, the priority to accelerate the termination of emergency condition shall be to improve the raising and distribution of emergency supplies. However, the time when a single index comes to steady situation can not be used as the maximum planning stopping time of emergency system, N, which can be determined only when the emergency system comes to a relatively steady situation. Therefore, it is possible to use Eq. 15 to get the distribution curve of

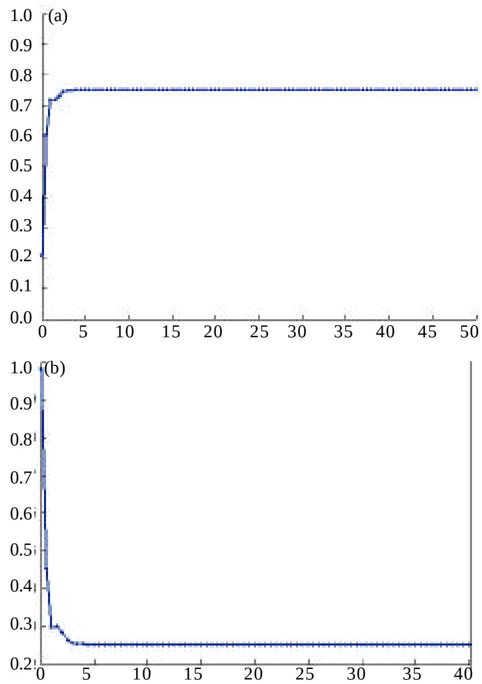

Fig. 5: Steady distribution of emergency system

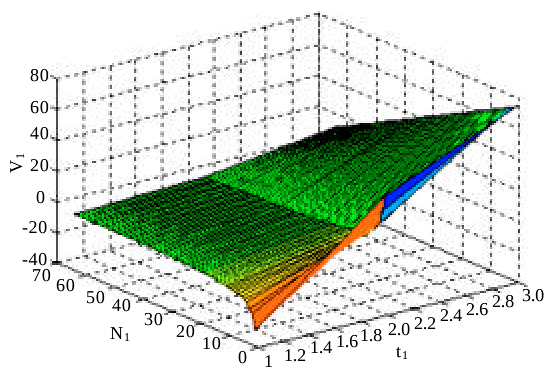

Fig. 6: 3D relationship between time efficiency M and t_n for emergency work

Table 5: Output of V_n,t_n

n	V_n	t_n
75	-38.000	
74	-28.627	37
…	…	…
39	-4.023	2
38	-3.965	2
37	-3.912	1
…	…	…
23	-3.410	1
22	-3.405	1
21	-3.400	0
…	…	…
1	-3.400	0

transition probability of emergency system as shown in Fig. 5.

As shown in Fig. 5, after the probability transition through 14 unit periods, the probability distributions of Tension Situation and Steady Situation come to steady distribution, when P (X_n = 1) = 0.25, P (X_n = 2) = 0.75 and maximum planning stopping time $_N$ = 75.

Stage 2: Deciding the optimal stopping time of emergency condition:

- Calculating the optimal termination time 1 based on the optimal stopping criterion of Standard 1. It is not necessary to perform iteration calculation to solve the key variable of optimal stopping r* by Eq. 20, but N =75 can be directly substituted into Eq. 23 to get r* = 27.59. According to Standard 1, it is not possible to make decision on the termination of emergency condition in the first 27 days, until the first day when the time efficiency M comes to the maximum value after 27 days (i.e., the mean time taken for demand satisfaction M_t comes to the minimum value), then it is the time that the emergency condition can be terminated. This M is the maximum value relative to those before, but not the absolute rank. Therefore, the highest probability to terminate on the first day when M comes to the maximum value after 27 days is 0.276
- Calculating the optimal termination window (a, b) based on the optimal stopping criterion of Standard 2. A program is set up according to the algorithm of Standard 2, outputting the results of stimulation as following (Fig. 6 and Table 5)
  As shown in Fig. 6, as $_N$ decreases and V_n increases, the corresponding t_n gets higher rank and V_n comes to the maximum value when t_n = 1. As shown in Table 4, the time sequence corresponding to t_n = 1 is {22, 23, …, 37}, which indicates that the optimal stopping time for the termination of emergency condition should be chosen within (a, b) = (22, 37) and optimal termination time is the time corresponding to the value of $_M$ with the highest rank. During the first 21 days, t_n = 0, which indicates that the emergency condition shall not be terminated during the first 21 days
- Making decision on termination of emergency condition. Based on Standard 1, it can be known that the key variable of optimal stopping time r* = 27.59, which means that the decision on the termination of emergency condition should not be made in the first 27 days. Based on Standard 2, it can be known that the optimal stopping window (a, b) = (22, 37), which means the termination time should be chosen within this window. For the purpose of making final decision, Standard 2 can be applied as the

verification of Standard 1, while each of them can be used independently. No matter which standard is used, it is required to find the maximum time efficiency that appears for the first time. As everyday's efficiency is not known in advance, the only approach is to narrow down the window for higher accuracy of decision making. Methodologically, it is feasible to combine the results of both standards: take the intersection (int [r*], N)∩ (a, b), marked as (c, d), then (c, d) = (27, 37), then the window can be narrowed down further. Theoretically, if the maximum time efficiency that appears for the first time is found, the corresponding time can be determined roughly as the termination time of emergency condition. In practice, the midpoint of this window can be determined as the termination time, based on which we can arrange and coordinate the following emergency works for higher efficiency. Similarly, the optimal stopping time based on cost efficiency can be decided too. If the two times decided above are different, the one decided by time efficiency prevails, which is in accordance with the characteristics of emergency works

CONCLUSION

Based on the stochasticity of the change of emergency condition, this study employs Markov chain decision-making method and Optimal stopping theory to study the issue of the termination of emergency condition, for which a stochastic decision model is developed to decide the termination time of emergency condition in stages. Stimulation case shows that this method is of high theoretical and practical value:

- Markov chain decision-making process is performed to study the maximum planning stopping time N for the termination of emergency condition. At first, the emergency condition is divided into two situation, namely tension situation and steady situation. Then, three indexes (Disaster Spread, Demand Satisfaction and Temporal Settling) are chosen to measure the emergency condition and function expressions are obtained by the Markov property of stochastic variables of emergency condition to describe the processes that these index approach steady situation through n-step transition, in order to set up the theoretical basis for maximum planning stopping time N
- Optimal stopping theory is introduced into deciding the termination of emergency condition, resulting to two standards to solve the optimal stopping time, which ensure to find the optimal stopping time within (0, N). Meanwhile, two optimal stopping models are established based on time efficiency and cost efficiency separately, which narrow down the window of termination time greatly
- A stimulation case is used as an example and it proves that it is practical and feasible to estimate the optimal stopping time by its key variable found in (0, N), where N is the maximum planning stopping time determined at first and the result is accurate
- There are many indexes that influence the termination of emergency condition, however, this study only chooses several indexes that are easy to perform statistical calculation, resulting to less accurate decision for the termination of emergency condition. At the same time, only single-factor-concerned model is established when Optimal stopping theory is introduced, allowing us to decide the key variable of optimal stopping time only, but not the time when the key variable comes to the maximum efficiency for the first time. The next phase of this subject is to employ high-precision estimation for more efficient decision making on the termination of emergency condition

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