The Framework of Termination Mechanism in Modern Emergency Management

Yannan Wu   An Chen   Yan Zhao

***Abstract*—**Termination Mechanism is an indispensible part of the emergency management mechanism. Despite of its importance in both theory and practice, it is almost a brand new field for researching. The concept of termination mechanism is proposed firstly in this paper, and the design and implementation which are helpful to guarantee the effect and integrity of emergency management are discussed secondly. Starting with introduction of the problems caused by absent termination and incorrect termination, the essence of termination mechanism is analyzed, a model based on Optimal Stopping Theory is constructed and the termination index is given. The model could be applied to find the best termination time point.. Termination decision should not only be concerned in termination stage, but also in the whole emergency management process, which makes it a dynamic decision making process. Besides, the main subjects and the procedure of termination are illustrated after the termination time point is given. Some future works are discussed lastly.

***Keywords*—**Emergency management, Termination Mechanism, Optimal Termination Model, Decision Making, Optimal Stopping Theory.

I. Introduction

IN real life people often lack the awareness of potential dangers in normal state as well as in the termination stage of emergency management. Emergency management is started when incidents occur, during the process of which many measures should be taken to control the development of incidents and rescue the victims, but its termination is always easily neglected [1]. As the last step of emergency response process, termination is a relative safe stage, in which stage dangers have almost been past, except that new problems may be brought by no termination or incorrect termination. According to historical cases, no termination or incorrect termination may cause disasters' recurring, new types of disasters, and also a waste of resources.

Disasters' recurring is a basic problem with a high probability, especially for natural calamities. Take Wenchuan Earthquake as an example. Over 207,000 aftershocks including eight over-six-magnitude aftershocks have been recorded until September 1, 2008. Besides, incorrect termination may lead to the occurrence of a new disaster. Once in a snow-covered mountain, a rescue team who has taken part in responding after a snowstorm was actually trapped there for several months only because the evacuation command didn't arrive in time. The main problem caused by no termination or incorrect termination is the waste of resources. Amount of urgent resources including people, materials, public attention and etc. are demanded in a short time due to the suddenness of occurrence and lack of preparation. If the resources are not released timely, it will bring huge losses not only to the disaster area also to other areas in the need of resources. Furthermore, agencies which are temporarily organized for response should not remain after emergency management, but most of them are not dissolved in reality which results in overstaffing with over occupied resources.

Many situations will lead to incorrect termination, for instance, incorrect time point to terminate, incorrect measures or termination procedure to be taken, and so on. However, how to determine the proper time point for termination is the most crucial issue in termination mechanism and even in emergency management. If emergency management was terminated too early, the following disasters would not be dealt with; conversely, unnecessary waste of resources would happen in case of no termination or late.

Until now, only some applications but few systemic studies in termination mechanism in emergency management have been built. Termination preparatory scheme and termination notice are the main forms of application, both of which lack of elaboration and operability.

This paper is organized as follows. Next section is the literature review. In section 3, the essential analysis of the concept of termination mechanism is presented. Then the termination index is proposed in section 4. Optimal Termination Model based on Optimal Stopping Theory is built in section 5. In section 6, this issue is expanded to the analysis of the dynamic decision making process of emergency management. The main roles and the procedure of termination are given in section 7. Simple summary and future work are given in the last section. Some key issues should be addressed explicitly, such as, termination time point, termination procedure and executive subjects, for the importance in modern emergency management.

II. Literature Review

Inappropriate termination of emergency response process will cause additional significant loss due to the intermittent occurrence of secondary incident, the waste of resources, and

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so on. Unfortunately, scarce researches on emergency management have paid attention to this issue. Most of the words related to "termination" appear as proper nouns in the papers on special fields, like medicine or chemistry. For instance, Jeffrey et al. [2] listed a variety of types of termination and concluded with a list of questions to assist practitioners in determining what type of termination is appropriate in a given circumstance and how to reduce risk for both the patient and the practitioner in the process. Bal [3] reviewed the state of the art of coolability during a severe accident for the current light water reactors and whether the accident management actions will be effective in terminating a postulated severe accident.

Deep researches are urgently required to enhance the application of termination mechanism. However, some related work has been done as the base of this paper.

Mechanism is one of the key issues in emergency management, which includes two different aspects: abstract analysis and concrete analysis. For abstract analysis, the mechanism system emphasizes the essential analysis of emergency management with four categories: principle mechanism, logic mechanism, process mechanism, and operation mechanism [4]. As for concrete analysis, the mechanism system is built to optimize each key link in the whole responding process of emergency management, which the termination mechanism belongs to. Many scholars have studied on other mechanisms except termination mechanism from this aspect.

For the warning link of emergency management process, Dokas [5] et al. argues that Early Warning Systems for engineering facilities can be developed by combining and integrating existing technologies and theories. Coordination mechanism is another important link, for instance, Yang et al. [6] proposed a multi-agent system architecture within which user and functional agents cooperate based on a collaboration mechanism, to better support computer integrated abnormal situation management (ASM); Becky [7] developed models of the implementation of the EMCRS for specified disaster scenarios, which support diagnosis of coordination problems between agencies. Afterwards, researches on assessment mechanism have also been existed for a long time. Iman and Eyke [8] presented a system for assessing the risk of natural disasters which employs fuzzy set theory to complement the probability theory with an additional dimension of uncertainty. David and William [9] described a quantitative risk assessment approach for hazardous materials transportation that has a strong emphasis on consequence modeling and employs considerable statistical data from past incidents.

Besides, Optimal Stopping Theory is the main mathematic tool in termination mechanism which is used to ensure the best termination time point. Optimal Stopping Theory has been widely used in practice especially in investment, and has many branches developed for the demands of different issues. Ludkovski [10] studied the numerical solution of nonlinear partially observed optimal stopping problems.Nikolopoulos and Yannacopoulos [11] proposed a model for optimal advertisement in new product diffusion based on the Bass model in order to determine an optimal stopping rule for the advertisement campaign. Szimayer and Maller [12] proposed a property that the filtrations generated at each stage by the approximations are sub-filtrations of the filtration generated by the continuous time Lévy process, which is useful for applications of these results, especially to optimal stopping problems. Alfred [13] considered the problem of optimal stopping of an independent and identically distributed sequence of random variables with observation costs and no recall for a decision maker, who maximizes expected utility.

III. Concept of Termination Mechanism

Although termination is critical to emergency management, few relative theories can be found in literature not only in emergency management but also in other fields.

It is believed that rehabilitation mechanism (short for RM) is the last step of emergency mechanism instead of termination mechanism (short for TM). Rehabilitation mechanism is designed for disaster recovery, which generally includes resource compensation, reconstruction in disaster area, conclusion and discussion, result assessment and etc. Although there is close relationship between termination mechanism and rehabilitation mechanism, their essences are quite different. Termination corresponds to a fast recovery after disasters, while rehabilitation implies a complete recovery stage. In other words, rehabilitation is slow and durable, while termination can be considered as a time point or a very short process. Fig. 1 shows the relationship between termination Mechanism and rehabilitation mechanism. Generally, termination occurs before rehabilitation in the sense that only after the emergency state is terminated does the rehabilitation stage start. Termination can be regarded as a necessary element of rehabilitation.

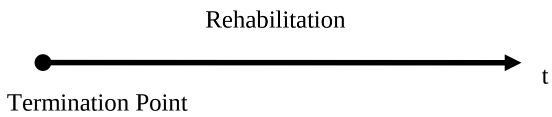

Fig.1 Relationship between RM and TM

When the emergency is terminated, it means the disaster is under control, or confined in a small range, in which period common measures taken by response agencies are able to eliminate the negative effects of accidents. At the end of emergency state, termination mechanism is used to ensure the results of emergency management by standardizing the relative activities, such as occupied resource release, temporary organization dissolution, etc.

Termination can be classified into effective termination, ineffective termination and injurious termination, as the influence resulting from termination. Effective termination adopts an effective method to decide the terminating time and also correct procedure to terminate the emergency, so it helps to dissolve the disaster smoothly, prevent or monitor the disasters' recurring. Ineffective termination does not terminate the emergency properly that we even cannot make sure whether the disaster has already gone. Injurious termination means the termination activities do not eliminate the disaster but cause other negative effects, e.g., new accidents or public panic.

Cycle is one of the top key issues in many researching fields. Emergency management cycle starts with launching mechanism and ends with termination mechanism. All kinds of decisions are made inner the cycle. The cycle loops when incident occurs every time.

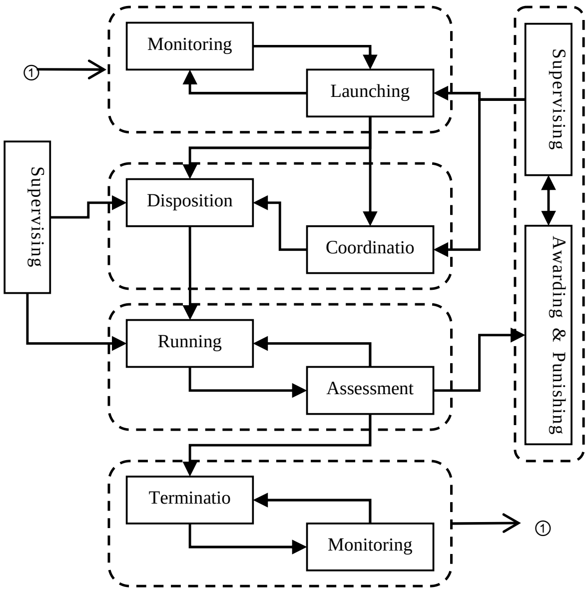

Fig.2 Logic Relationship of Emergency Management Mechanisms

①—Normal state with risk recognition

As shown in Fig. 2, termination mechanism is the connection point between emergency state and normal state in the emergency management mechanism system. Including Termination Mechanism, emergency management mechanism consists of eight mechanisms: Monitoring, Launching, Disposition, Coordination, Running, Assessment, Supervising, and Awarding & Punishing Mechanism. Monitoring mechanism runs before launching mechanism, termination mechanism corresponds with launching mechanism, and the other mechanisms go through the whole process of emergency management. Remarkably, termination and launching process are almost reversible. Provided the changes before and after the emergency can be neglected, the exit of termination mechanism is also the entrance of launching mechanism, which is the same risk recognition process associating monitoring mechanism in normal state. Termination mechanism is important to terminate the emergency management and to enter the next cycle.

IV. Termination Index

To select the best and only time point for termination, a termination index (*S*) including many indicators is proposed to evaluate the current state to get the answer to whether to terminate. The higher the value of *S* achieves, the more appropriate to terminate the emergency management process. The assessment of termination is a multi-criteria decision making problem. Four categories of these indicators can be classified: disaster itself (*D*), public panic (*P*), resource allocation(*R*), and future cost (*C*).

1) Disaster itself (*D*).

The indicator *D* is a continuous variable of which values must range from *0* to *1* (*0* is excluded). Set *1* as the degree of the greatest disaster of the same type in history, then the current value can be given from comparison. The degree should be considered from two aspects, the disaster grading (D_1) and affected area (D_2). For D_1, most of incidents have their special class partition, especially natural disasters. For example, hurricane can be divided into 5 grades according to the maximum sustained wind speed, storm surge, the minimum central pressure. Due to the different release of energy and intensity, earthquake is divided into 12 seismic rating respectively. Consequently, the severity of the disaster can be determined by the grading. For instant data is insufficient to represent the current status of disaster, it is suggested to use average data collected in a period for assessment in practice. For D_2, its value increases when the disaster is still spreading and expands to larger area. Therefore, a simple formula can be written as:

$$D = D_1 \times D_2,$$

Obviously, *D* is inversely proportionate to the termination index (*S*).

2) Public panic (*P*).

The damage to people’s normal life may be the severest loss caused by emergencies. People in both the disaster area and non-disaster area cannot live a normal life, because everyone is a member of the society, in which “one change makes all change”. In addition, people in non-disaster area pay so much attention to the disaster and rescuing activities that their attitude becomes a direction to responding process rather than in the disaster area. Public panic (*P*) is a measurement variable which indicates the main response of public (definition in [14]). If the value of *P* is relatively low, public response leads a positive direction which means the value of *S* is high; conversely, the public hold a negative view and the emergency management cannot be terminated. In [14], the indicator *P* is defined as follows:

$$P = \sum_{i=1}^{M} \left[D'_i \sum_{j=1}^{N} Affect_{ij} Factor_{ij} C'_{ij} \right],$$

Where *P* stands for the degree of public panic, D_i, $Affect_{ij}$, $Factor_{ij}$, C_{ij} are factors affecting the value of *P*. D_i and C_i in this formula are not the same with the indicators of disaster itself (*D*) and future cost (*C*).

3) Resource allocation (R).

When incidents occur, plenty of resources should be needed and transferred to the disaster area, which should be settled reasonably to avoid unnecessary losses. Resources involved can be divided into two parts, resources which have been consumed (R_1), resources which are storing (R_2) and resources

International Journal of Business, Human and Social Sciences
ISSN: 2517-9411
Vol:4, No:6, 2010

which have not been in place (R_3). R_2 should be dealt with when execute the termination, and R_1 and R_3 determine the time point to terminate. The more R_1 are the better to terminate. Then R should be calculated according to the following formula:

$$R = \frac{R_1}{R_1 + R_3}$$

4) Future cost (C).

Economizing on resources is one of the important principles that should obey during emergency management, though the task of rescuing is urgent. The estimate of future cost (C) can be calculated in advance to know whether the objectives are worth rescuing. If C is increasing, termination should be concerned, though it probably not has to terminate.

From above, the relationship between termination index and indicators has been put forward. Provided each indicator impacts on the result of evaluation independently, termination index (S) can be defined as:

$$S = \frac{1}{D} \cdot R \cdot \frac{C}{P}$$

It should be noted that the formula to calculate S can be expanded using more variables, for disasters and responding measures vary all the time.

V. Optimal Termination Model based on Optimal Stopping Theory

In this part, a model is built to ensure the best time point to terminate, which we call Optimal Termination Model. It is based on Optimal Stopping Theory, using termination index (S) to measure the current state and make a decision on whether to terminate. Then an example is given to explain the model. Take the value of S as the estimate of current state at each time point.

A. Optimal Stopping Theory

Optimal Stopping Theory is an important branch field of probability theory, which aims to find the best stopping time point to get maximum profits. Depending on the various probability structures and return functions of the problems to be solved, this theory consists of many solutions based on different hypotheses, for instance, under finite as well as monotone situation. Nowadays, Optimal Stopping Theory has been in practice mostly in finance industry.

It is incorporated to solve the termination problem in emergency management. For each time point in emergency management process, a numerical variable like profit in Optimal Stopping Theory can also be found to measure the current state. Then the best termination time point can be chosen by the values on all candidate time points. The optimal termination time point or optimal termination rule (T) is easy to be acquired when the same hypotheses are satisfied.

B. Description and conclusion of Optimal Termination Model

To simplify the issue and also prevent no solution to be outputted, the model is constructed under the hypothesis of finite situation. Complicated models can be researched into underpinned by this model.

Finite situation implies the optimal termination time point must exist in a specific time domain. Incidents often break out at a sudden time with a starting point and the corresponding responding process ends eventually. Though the end time cannot be obtained in advance, a fixed number (N) can be set to guarantee the emergency management process is time-finite, which is large enough to consist of all the probable termination time point. Therefore, the premise of finite situation has been proved feasible.

For the final result is time data type, the random variable to be modeled on should also be set with time units. The setting of N can be carried out by experience. For example, N in a small traffic accident should be set as 2 to 3 days, while in an earthquake N should be 1 to 2 months (or 30 to 60 days). The chosen value of N is vital to the conclusion of the model. The time unit is selected by demand, which means the time length can be calculated by hour or by day. Day is of common use.

In this model, the specific value of termination index (S) is disregarded. The truly needed data is the sequence after sorting the values of S, which is also the base of return function. The values of S on each time point cannot be known before formal termination, though the definite order can be given after termination, which we call absolute sequence. A sequence of S is donated as $S(1)$, $S(2)$,…,$S(N)$, with $S(1)$ as the maximum value of S, $S(N)$ as the minimum one. Theoretically termination should be executed on the time point with $S(1)$.

In the during-incident stage, the absolute sequence is still uncertain, but we can know the accurate sequence of S of n days on Day n, which is called relative sequence. The relative rank of Day n is donated as y_n. So a random sequence of 1, 2, …, N can be acquired in reality.

Assume the values of the return function on successive two days are never the same, in other words, there are not nodes. This assumption accord with reality, for the uncertain development of incidents brings different cost and result on each day, which contributes to the change of the value of S. Even if there is a node, common methods can be used to deal with, like setting the average value of the ranks instead on those days of the node.

Thus, the optimal termination time point issue can be converted into a problem with two different objectives:

Criterion 1--make the chosen time point emerge the maximum value of S with the highest probability;

Criterion 2--make the chosen time point gain the minimum value of its average absolute rank.

According to Optimal Stopping Theory, the optimal termination rule (T) which can be acquired from backward induction is written as follows: [15]

Theorem 1 For Criterion 1, $T = \inf\left\{n \ge r^* : y_n = 1\right\}$,

Where $r^* = \inf\left\{r \ge 1 : \frac{1}{r} + \frac{1}{r+1} + \ldots + \frac{1}{N-1} \le 1\right\}$, and $\lim_{N\to\infty} V^N = \lim_{N\to\infty} \frac{r^*}{N} = \frac{1}{e}$.

The chosen time point is the one satisfying *T*.

Theorem 2 For Criterion 2, $T = \inf\{n \geq 1 : y_n \leq t_n\}$,

Where $t_n = [-\frac{n+1}{N+1} \cdot V_{n+1}], n = N-1, N-2, ..., 1, t_N = 0$,

[ ] stands for rounding operation, a $\wedge$ b stands for min (a, b), And

$$V_N = -\frac{N+1}{2}, V_n = -[E(\frac{N+1}{n+1})y_n \wedge (-V_{n+1})], 1 \leq n \leq N-1$$

The chosen time point is the one satisfying *T*.

C. Example

The application of the optimal termination model and its conclusion is explained by the example below.

An earthquake at about 6.5 magnitude occurred in a certain area, resulting in over 100 deaths and huge damage to buildings and residents' normal life. Though the relative agencies immediately started the emergency management process, the effect was decreased by the continuous aftershocks. Which one is the optimal termination time point?

According to historical experience and live situation, N can be set as 100 days. Day is chosen as the time unit for the disaster was quite severe.

Then calculate r^* with the conclusion of Criterion 1. When N=100, $r^* \approx 36.8$.

The chosen time point to terminate is the day after the 37th day with the maximum value of S compared to previous values. The maximum value is not its uncertain absolute rank but relative rank.

In the mean time, we also know the probability that just the day with maximum absolute value is chosen achieves at 0.368 which is the highest. Besides, the set value of N is critical to the result.

VI. Dynamic decision-making process

Evaluation of the current state should be carried on before termination, that termination mechanism actually covers the whole emergency management process. The design of termination mechanism cannot be independent to the emergency management process, so the value of S at each time point can be still as the estimate of current state.

The emergency management process would continue when the wrong time point to terminate was chosen, due to the greater disaster it might cause. Therefore emergency management becomes a dynamic decision-making process. To take more measures or terminate should be decided on each time point.

A. . Ideal Emergency Management Process Analysis

In order to easily analyze the termination rule on those candidate time points, the curve of ideal emergency management is given (see Fig.3). Time acts as the horizontal ordinate, while S is the vertical ordinate. Provided the curve is a smooth line, with many candidate time points joined together. Although the real emergency management may never like this, the basic optimal termination rule can be acquired from the curve. In Fig.3, the dotted line stands for the possible emergency management in reality.

Huge damage is caused when incidents occur, on which time point we set the initial value of S as S0. For the suddenness, people have no time to get prepared, so the value of S still decreases when emergency management starts. However, the speed declines because relative measures have begun to carry out (see (0, t_{min})). Then the value begins to crawl up, in the case that correct measures and decisions have been taken, till the maximum value at t_{max} in (t_{min}, t_{max}). To hold the effect of emergency management, we should terminate at t_{max} in ideal state.

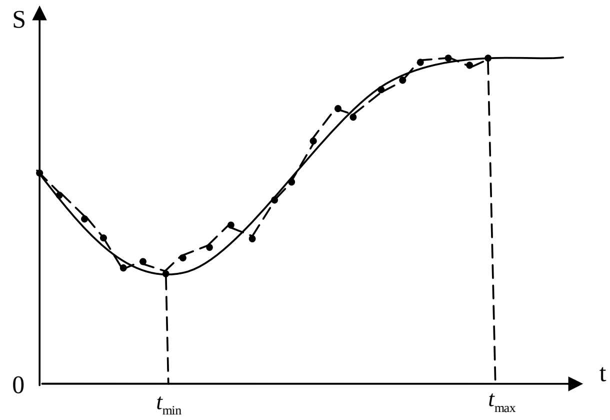

Fig. 3 Ideal Emergency Management Curve

Even in ideal state, there are surely more than one extreme points in emergency management process, including points of maximum and points of minimum. So we prompt a flow chart to illustrate the process with many extreme points (see Fig 4).

Intensive measures should be taken to slow down the development of incidents occurred when S is decreasing. However, we just need to maintain existing measures when S is increasing after the points of minimum. Decisions don't have to be made until S achieves the points of maximum. Both new disasters and wrong decisions which make S fall may occur at each point of maximum except the last one.

At this time new evaluation should be underway on the emergency management process, and new measures are needed to reduce the margin value of S. Termination should be carried on when the maximum profit reaches.

Remarkably, during the monotonic increase or decrease of S, the changing speed alters from low to high and then to the converse. In other words, the influence produced by the disasters cannot be weakened at once; on the contrary, the effect can be obtained through a period of accumulation.

In ideal state, the time point, on which the maximum value of S reaches, which is also the best termination time point, can be easily found. However, the reality will not always accord with our expectation.

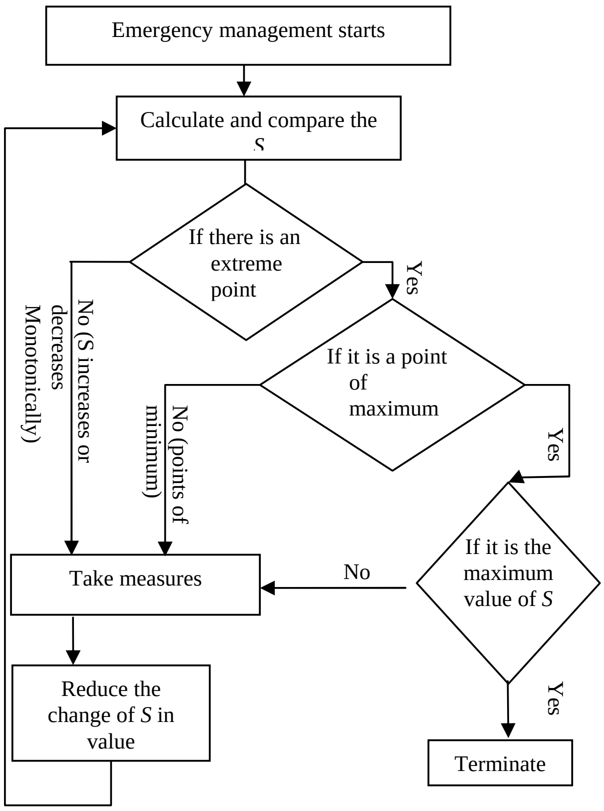

Fig. 4 Emergency Management Flow Chart

B. Real Emergency Management Process Analysis

How to determine the best time point for termination in reality? As the dotted line shows in Fig. 3, the points which stand for values of S would not exactly locate on the smooth line of ideal emergency management, even if the function of S is the same. Points of the real values of S scatter around the ideal curve. If we made decisions whenever the extreme points are met, we would pay some unnecessary efforts and in the meantime would be led by the results caused by each decision. These values of S on many candidate time points fluctuate temporarily, so we can never forecast the next stage of emergency management process.

Optimal Stopping Theory is still incorporated to solve the dynamic decision-making problem. We are not only to look for a best time point to terminate but also consider the emergency management process as a dynamic decision-making process. The model built in section 3 is not available any more, therefore Bellman equation is built with S instead of the previous return function.

Bellman equation is an appropriate tool to expand the issue on optimal termination model into the issue on making decisions on each time point in the emergency management process. Bellman principle of optimality means whatever the decision at time t the following decision is optimal forany time after t+1. The Bellman equation is formalized as follows: [16]

$$V(y_t, t) = \max_{z_t} \{F(y_t, z_t, t) + V(y_{t+1}, t+1)\},$$

Where yt is a state variable, zt is a control variable, t stands for the time, F stands for the attainable profit, V represents the optimal solution at some time. The previous model in section 3 depends on not the values of S but the sequence of the values of S. If the return function was changed into a Bellman equation, the values of S would be used to improve the model, which emphasizes the importance of measuring the current state.

We divide the value of S at t moment (St) into three parts, which means S equals to the sum of S_t^+, S_t^- and S_{t-1}. S_{t-1} denotes the initial value at t moment, which is also the value of S at t-1 moment; S_t^+ represents the positive benefit, which is acquired when the influence of the disaster and public panic reduces, or effective measures are taken, and so on; S_t^- stands for the damage caused by spreading disasters, negative measures, and etc. Therefore the changes of S can be clearly watched and different weights can also be set for different parts of S to increase the accuracy of return function. Then the new formula of return function is

$$V(S_t, t) = \max_{S_t^-, S_t^+} \{F(S_t, S_t^-, S_t^+, t) + V(S_{t+1}, t+1)\}.$$

The solution of this formula will not be discussed in this paper. Making decisions on whether to terminate or to continue carrying out measures makes emergency management a dynamic decision-making process.

VII. Roles and Procedure of Termination Mechanism

The termination stage can be started after the time point we choose to terminate. During the termination stage, three main roles are involved with different tasks, which include governments, experts and the public. The implementation of termination is dependent on those roles.

1) Government: decision-maker

The government refers to the related organizations responsible for decisions making, command unification and resource distribution during the whole process of the emergency response. On the premise of ensuring the effect of emergency management, the government should make the final decision and join all the termination activities based on the assessment of experts and the public response.

2) Expert: strategist

Experts analyze the current status according to their knowledge and scientific tools and provide the government with professional proposals for supporting decisions. Experts may develop different termination index systems for real-time assessment and submit the results to decision-makers. At present many experts are members of government, but they have less right to make decisions.

3) Public: key factors affecting

To some extent, both the decisions of government and the suggestions of experts depend on the public response. Although public do not participate the decision-making directly, they play an important role to determine the rhythm of termination activities. It is not a proper time to terminate if the public still hold strongly negative views of the emergency.

In order to achieve desired effect of emergency management, the implementation of termination should follow the correct procedure (see Fig.5). Firstly, government should publish the termination notice which defines the executing procedure and informs the related organizations. Secondly, the lower-level organizations execute the program, dissolve temporary measures or transfer them to regular measures, recycle resources, and so on. For instance, after a traffic accident has been dealt with, the police should evacuate and remove the warning sign at the accident location. Afterwards, the members are required to submit a summary report to the government or higher-level organizations. Finally, the temporary organizations should be disbanded after the members are properly resettled.

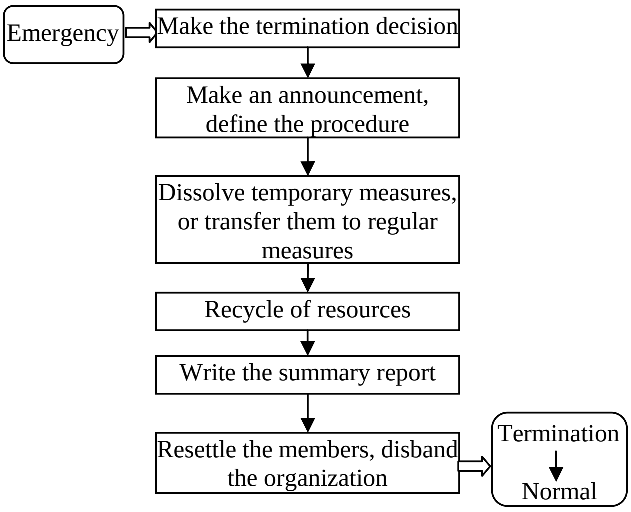

Fig. 5 Termination Execution Program

VIII. CONCLUSIONS AND FUTURE WORK

This paper presents some key issues on termination mechanism, including analysis of absent termination and incorrect termination, termination index, and roles and procedure of termination, and especially the analysis of dynamic decision making process based on optimal termination model. All the above are main parts of the framework of termination mechanism in modern emergency management. It helps the emergency responding process integrated,

Optimal Stopping Theory is incorporated as the kernel of termination mechanism, though the model built in this paper is an initial application with a simplified hypothesis to the issue of ensuring the best termination time point. In further, more complicated hypothesis based on probability and also more accurate return functions both of which are the main branches of Optimal Stopping Theory will be used to construct the model. Besides, more useful mathematic tools, especially the optimization methods, will be concerned in the framework of termination mechanism, to acquire more convincing conclusions. More accurate solutions of models can support different decisions during the dynamic decision-making process.

ACKNOWLEDGMENT

This research is supported by the State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University (Contract No. RCS2009K002), Collaborative Team of Chinese Academy of Science & Beijing Academy of Science and Technology (Contract No. 0800641301) and funded by the project of Mass Crowd Risk Early Warning System of Xidan Area from Beijing Municipal Institute of Lab.

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