Multi-Signal Cooperative Decision for Emergency Management Inspired by Immune System

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***Abstract*—Various disasters with serious results are reported and happen around our lives. Most of them are unconventional contingency events that are difficult to be detected and discriminated. Emergency management is an important activity dealing with the contingent events. For the uncertainty, imperfect, stochastic, fuzzy and disturbed environments and the unrecognized characteristics of the events, it is hard to make the urgent decision in the context of emergency management. Inspired by the higher efficiency and special structure of immune system dealing with the pathogens, a multi-signal decision model is proposed to model the decision process in emergency management. A series of decision models and flow are designed to consider the context of emergency management. A framework of decision support system is designed to incorporate the multi-signal decision model for practical emergency management. However, in the model and the framework, some valuable directions are raised and are being studied under the way.**

***Index Terms*—Emergency management; Immune intelligence; Danger theory; Multi-signal decision; Emergency decision**

I. I. INTRODUCTION

Various disasters deprive the home and families from many people in the world. The lives and properties are facing various contingent events which induce large disasters. They are difficult to be predicted and it is too urgent to prepare for it. Emergency management has become a hot research field. Because of the complex environments of them and their unrevealed evolving principles, it is very difficult to collect the event status, organize the emergency prediction, preparation, relief and recovery. The emergency decision recalls novel principles for the uncertainty, imperfect and dimension-missing information and the urgent decision requirements. Although there are many uncertainty reasoning and decision approaches aiming at the similar conditions, facing the complex and urgent emergency management, they are weak in practice usage.

The immune system can be taken as an effective emergency management organization in body with valid emergency detection, response and decision mechanisms. In order to protect the body from invaders and maintain the stability of the body, there are many specific principle models and structures. Its mechanisms and principles have been extracted to design intelligent algorithms and systems. In order to detect the pathogens and destroy them, the immune system organizes the immune components to complete the tasks. Danger theory is a novel immune theory to explain the principles that immune system expresses its immune functions by. Multiple signals are involved in the theory. It is believed that the immune function is activated by the danger signals that are confirmed by a second signal. The co-stimulation signal calls the second the signal to make sure the invader. Therefore, the system can make decisions to destroy them without wrongly damaging the immune cells.

The main contributions of the study include the following points. First, the multi-signal mechanism in immune system is extracted, which will become a part of the field of immune intelligence. Second, inspired by immune system, the multi-signal decision model is proposed in the context of emergency management. Third, a decision support systematic framework is proposed to incorporate the multi-signal decision model for emergency management.

The remaining of this paper is organized as follows. In Section 2, we introduce the background including emergency management, immune intelligence, and the immune multi-signal model. In Section 3, the multi-signal decision model is proposed for emergency management. In Section 4, a systematic framework for emergency management is designed to incorporate the multi-signal decision model. In Section 5, we conclude the paper with some remarks as well as future research directions.

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II. BACKGROUND

A. Emergent management

Emergency management has emerged as a hot research field as artificial or natural disasters may occur anytime around the world with enormous serious consequences. Such disasters need quick-responsive emergency systems for efficient emergency relief and recovery. Although emergency management is vital, it has also raised numerous challenging issues, which may not be addressed as easily as common management systems. Some researcher have devoted to the field and published

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some important achievements. In the following, the research literatures are summarized.

In emergency management, there are many game relations among contingency events and response strategies, various levels of departments. Decision support platform and mechanisms [1-3] are effective approaches to coordinate the relations. Game theory [4] and improvisation decision technology [5, 6] are two prominent theories for emergency decision. Logistics is the main support tool for emergency management, especially for emergency relief. Emergency logistics has become a hot field in emergency management research.

The researches on emergency decision are mainly focused on the emergency resources preparation and scheduling by emergency logistics.

In the research of design theory of emergency logistics network to provide emergency resources, a hierarchical network for the time-definite express common carriers is proposed in [7]. A emergency response model is studied for military or non-military in [8]. In [9], an artificial emergency logistics planning system is proposed for severe disasters. In [10], the dynamic logistics coordination model is proposed to support emergency relief. These achievements focus on the path scheduling problems for different logistics network and emergency constraints. Commonly, only the single transport means is considered. In [11], a scenario planning approach is proposed under the uncertainty environments for flood emergency logistics. In [12], the optimization approach based on ant algorithm is study to reduce the disaster effects. In [13], the hybrid fuzzy clustering optimization approach is proposed for coordination in logistics distribution under urgent demands. In [14], the time-space network model in emergency response is proposed for roadway repair and subsequent relief distribution. In [15], the emergency logistics planning model is proposed for natural disasters. In the proposed logistics planning model for decision support system, in the determined time range of plan, when new suppliers or transport means are available, or there are new requests for relief resources, the model is built to optimize the vehicle routing problem and the loading/unloading problem so that the time-dependent dynamical transport problem is solved. In scheduling optimization of emergency logistics system, the present research focuses on the efficiency improvement. In [16], a multi-objective optimization approach is proposed for emergency logistics distribution. The objectives are aggregated into a single objective by a weight vector. The time and cost of distribution are main constraints of the model. In the path optimization of emergency logistics, the time objective is mainly considered to be minimized. The holistic network model for emergency logistics is not studied by researchers yet.

In order to decrease the uncertainty of emergent demands, the robustness of the emergency logistics network should be improved. The emergency logistics scheduling should consider the stochastic dynamic network. In [17], the road network robustness for avoiding functional isolation in disasters is studied. In [18], a two-stage stochastic programming framework for transportation planning in disaster response is proposed. In [19], a multi-objective path finding approach in stochastic dynamic network is proposed with application to routing hazardous materials shipments.

B. Immune intelligence

Artificial immune system is a computational intelligence paradigm, which has found applications in data mine [20], scheduling [21], control [22], machine learning [23], security [24], optimization [25], and many other fields [23]. However, most studies are limited within several immune principles and models, including clonal selection, negative selection, immune network, and danger model, which are utilized independently. Moreover, these studies focus on the immune algorithms to improve other algorithms or to serve specific problems.

In the biological view, the components and principles in immune system do not operate in isolation, but act as a whole by delicate organization. The cytokine network is an important way to support coordination among immune components. Based on these principles, a few studies have captured some systematical requirements and proposed some models and frameworks for security of information systems or networks. For example, a distributed defense system is studied inspired by the danger model of immune system [24]. In our previous study, the evolutionary features in these frameworks should be studied and applied in multi-objective optimization[26], the distributed computing systems [27, 28] and co-evolutionary design [29]. There are many models, principles and concepts in immune system. They can be employed to build models or design intelligent mechanisms for complex systems.

C. Immune multi-signal model

In 1994, Polly Matzinger proposed the Danger Theory [30-32]. It is believed that immune response is activated by danger signal other than “self/non-self” discrimination (SNSD). The primary reasons are: first, body does not necessarily response to any foreign invaders; second, “self” in the life of individual is ever changing. However, the SNSD theory presumes that the individual immune system learned how to discriminate “self” and “non-self” in the early stage of its life. The Danger theory emphasizes the danger signal which does start up the immune response. In this hypothesis, tissue in the center position controls the entire process. As shown in Fig. 3, the cells in the body can send “danger” (Sig II) or “alarm” (Sig 0) signals to APC cells when they are in danger status or even natural so that APC can be activated in local. Although the theory is lack of experimental proofs, it has been applied to explain many immune phenomenons. Especially, many models and algorithms are proposed for information or network security problems inspired by danger model.

In Danger model as shown in Fig. 1, the SNSD is included. B Cells can discriminate the invaders by “self/non-self” discrimination theory, and Sig I are produced and sent to T Helper cells. After the T Helper informs the T Killer cells, the invading pathogens will be eliminated. In another way, normal cells, especially distressed cells, can send alarm signals (Sig 0) to APC and APC can also detect pathogens, followed by which co-stimulation signals are sent to T Helper cells. The difference of Danger model is that only Sig I without confirm signals, Sig II, the immune system tolerates the invaders. Sig I with cooperative Sig II can successfully activate immune response.

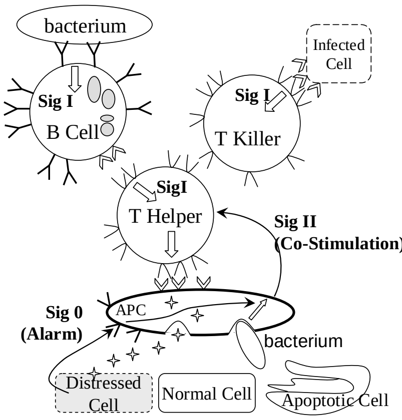

Fig. 1. Danger Model

The signals in the Danger model coordinate to determine the status of the invaders and try to destroy it in an effective way. The metaphor can be simplified into a multi-signal model for decision. The levels of signals determine different detection and decision aspects with different importance or other specific features for decision. The cooperation among them finally makes the decision more effectively. The immune system itself can be taken as an emergency management organization to protect the body and deal with the invader, which can be taken as outer contingent events.

III. MULTI-SIGNAL DECISION FOR EMERGENCY MANAGEMENT

Inspired by the multi-signal model in immune system, a multi-signal decision model for emergency management is proposed. In the following, the decision model is studied.

A. Periods of emergency management

There is no well-accepted classification model of periods in emergency management for its complexity and variances of environments. In the context of multi-signal decision, the variance of decision in emergency management is focused so that the four-period is drawn as Fig. 2. In practice, before the emergency response for relief, there are too many uncertainties and disturbances so that the decision is difficult to be made. There are two periods are classified, detection and preparing. As soon as the emergency condition is determined, for the weak economy and urgency of the emergency relief, with the support of the government, enterprises and society, the emergency of relief and discovery can be under delicate control.

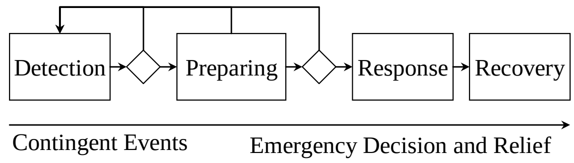

Fig. 2. The four periods of emergency management

In the period of detection, various sensors in the form of physical devices of society organization construct the detection network to collect the information of hidden contingent events. Then, the information will be used to judge whether there is event to happen, and to decide whether the preparing process should be started up or not. It will produce huge cost if the preparing process is started. However, for the time problem, if it is not prepared, the risk will be higher. After the prepare process is started, it can be canceled when the contingent event is confirmed to be eliminated or the detection information is unreliable.

Therefore, in the first two periods, all decisions are conducted based on the information of contingent events. The uncertainty is the main feature. It is difficult to construct a common theory for it. In the second stage, the other two periods, the scheduling of the resources is the main job. Compared with the former, it is more determined.

Because of the increasing frequency of huge disasters and unconventional contingent events with serious social damages, the detector network and the resource provider network are gradually settled. The possibility and accuracy of emergency prediction will be more and more correct. In another aspect, considering the heavy damages, the higher risk and cost can be accepted by the governments and societies.

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

B. Two-signal decision flow in detection and preparing

As studied in the previous subsection, the detection and preparing periods are full of uncertainties and lack of determined decision approaches. In Fig. 3, the decision process flow is summarized. The detectors are sensors around the possible sources of contingent events and environments. The convenient or cheap set of them provide the $SigI$. After the information fusion process and simple judge process to determine its validity and reliability, the risk evaluation process will compare the accepted signal with the feature of database of contingent events and decide whether the co-stimulation signal should be sent. All these processes of decision are conducted by the principles of contingent events, and the main purpose is to predict its status. In Fig.3, the decision process involves the discrimination of contingent events and the resources. It is called contingent events because it is difficult to be predicted in advance. Therefore, the relief in time and the lower cost are focused on. The decision process determined whether the prepare process should be started. The type, degree, scope and the predicted evolutionary processes are the results of decision about the contingent events. Moreover, they are inputs for resources scheduling. The prepare process is coordinative process among different departments of resources providers and the emergency management organizations. The time, cost and feasibility are important information to be considered in resource preparing schedule.

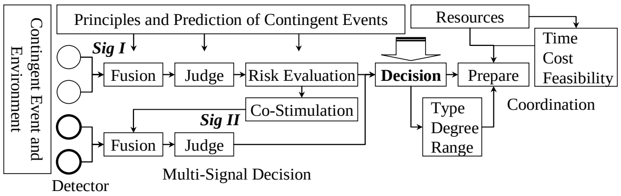

Fig. 3. The detection and preparing flow in emergency management

The decisions for the status of the contingent events are achieved by the two-signal model. By co-stimulation, the decision will start the detectors for confirmation with different signal collection devices or technologies. They will be taken as confirmation. Of course, they are commonly expensive so that it can not be used as daytime signal collection. The need of the second signal may involve the following reasons. First, the signal collection process involves cost and time. Second, there are full of complex uncertainty so that single type of signals is insufficient to judge the event type and strength. Third, the complexity of contingent events makes it difficult to confirm them and discriminate them without multiple aspects of feature data.

C. The detailed multi-signal decision flow in detection and preparing

The practical environment of contingent events and their evolving principles are far more complex than the conditions that two-signal model can represent. However, because of the urgency of emergency management, and its impossibility to obtain the perfect information for judge and decision, the simplified multi-signal decision model has its feasibility and rationality. In Fig. 4, the process flow is depicted to show the detailed steps of the model considering the complex environment.

Although it is accepted that it is impossible to predict the contingent events and prevent it with exact valid approaches, the detector network is still keeping track of the possible sources and environments of the contingent events. How can the detector network be designed is another important topic in information acquisition field full of challenges.

The detectors in the network have two types. One keeps track of the contingent events all the time in fast, cheap and convenient way. Correspondingly, they can detect the exceptions but can not make it sure. Compared with normal status, the emergency status is still exceptional. It is impossible in economy and possibly technology to inspect all the possible contingent events in the same higher level. However, another type is a more expensive and precise detection way. The possible contingent can be confirmed by this signal in a large extent. Because of the complexity of the real-world emergency, it is impossible to judge the status very exactly before its explosion.

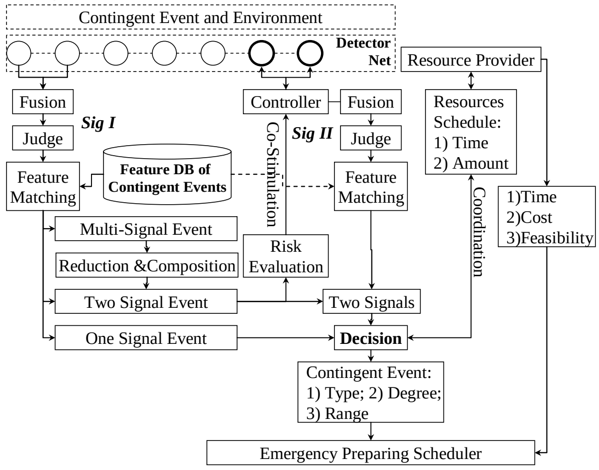

Fig. 4. The multi-signal decision process for emergency management

After the signal is collected, in the judge process, the concrete type or type set of contingent events will be determined by matching the features in the database. The history rule data and experiment discrimination knowledge are important in this stage. In this study, it is not deeply studied. However, according to one type of signal, it is difficult to judge the type of contingent event for its complexity. The uncertainty reasoning theories are employed to discover the event types. The result events are classified into three categories in this study. First, the one-signal event can be determined by a single type of signal. In theory, it may exist, for contingent event, it looks impossible. Second, the two-signal event can be determined by two signals, the $SigI$ and $SigII$. The different features of the two signals have been studied above. Third, the multi-signal events can not be confirmed by two signals. Maybe any contingent event is multi-signal events. However, as studied above, it is impossible to collection all exact information of it. Therefore, by analytical and reasoning skills, it must be transferred into two-signal event. Therefore, the contingent events are all unified into two-signal events and the can be deal with the same principles and models. In an alterative explanation, the multi-signal can be divided into multiple hierarchies of two-signal. Therefore, the reasoning and the judge skills can be used to make the decision.

The multi-signal is transferred into two-signal, where the risk is raised. First, it is simplified approach, where the dimensional information is neglected. Second, the two signals or one signal is determined by the principle on history information, which can not represent the evolving characteristics of contingent events. The risk evaluation knowledge is still not focused here.

Then, the request for the $SigII$ is raised by sending the co-stimulation signals to the controllers of the corresponding detectors followed the same flow of the first signal to obtain the judge. By incorporating the two signals or hierarchies of it, the decision should be made, to prepare for the event or not. The confirmation of the first signal produces cost. However, the preparing process will produce large cost. The decision is made by the authorized emergency management organization and executed by the resources provider. The preparation is to reduce the response time delay. The event type, scope and degree are main information for preparation. The decision maker and the providers will coordinate to make the preparation schedule. The time and amount for the specific resources and the feasibility for emergency relief are the main response information from the providers.

It is noted that the two-signal decision works in a continuous way during the whole decision process with levels. Therefore, the decision will be altered according to the evolving status of the hidden contingent events. The decision can be overwhelmed. The preparation process can be cancelled or suspended. The main purpose is to balance the cost and the urgency.

IV. Emergency Management System Based on Two-Signal Decision Model

With the inspirations and the features of emergency management, the multi-signal decision model is studied in the previous section. In this section, the framework of the decision support is studied.

An information management and decision support system is proposed to incorporating the two-signal decision model. In Fig. 5, a framework of the decision support system is shown for emergency management. The system is composed of seven modules.

(1) Detector management and data acquisition is a module to manage and control the detector network. It provides the signal data for decision. There are several tasks. First, the design and deployment of the detector network largely determine the managed contingent events and the possibly signals to be detected. Second, the design of detector devices or mechanisms tries to collect the information from various sources representing the status of contingent events. Third, the signal filter, information fusion, cleaning and transferring are to generate meaningful input for the feature matching module.

(2) The feature matching module finds out the matched types of contingent events by comparing the signal features with the feature database of contingent events. In this module, the pattern matching and other matching skills will be employed to find out the events with probability or trust levels.

(3) The feature knowledge management module maintains the database of features of contingent events. The contingent events are evolving so that it is critical to settle a perfect database to manage the features of them. The form of the knowledge can be production rules, or other representation of knowledge for decision. After each explosion of contingent event, the database should be updated a lot to improve the quality of the origin dataset, and append new set of rules.

(4) The multi-signal decision model is a key module to manage the signal composition and the flow. First, by feature matching, the contingent events are to be judged. Second, the event types, one-signal, two-signal and multi-signal are decided. Third, the multi-signal is transferred into two-signal. Fourth, the risk is evaluated by the risk management module. Fifth, the confirmation signal is activated and processed.

(5) The risk management is to provide systematic ways to reduce the risk in the uncertainty environments. The signal reduction model makes the decision faster and more feasible with the cost of higher risk. However, without faster decision, maybe higher risk will be faced.

(6) The preparation decision module decides to prepare or not prepare for the possible contingent events. If it is prepared for, the emergency relief will be more effective, where as it produces large cost if the event is not explosion. Facing the possibility of huge disasters, the optimization skills should be employed. But the importance is to make the rules for decision under the settings of practical resources and supports from the government and society. Various decision models can find their positions and value in this module.

(7) The integration and coordination module makes the system a whole with efficiency. There are two types of integration. The first is between the different levels of emergency management organizations. Commonly, they are organized in a hierarchy form. The second is between the emergency management organization and the resource providers. Of course, at the same time, the coordination among them helps to keep the higher efficiency of operations.

By the above seven modules, the two databases, the system can be constructed to support efficient multi-signal decision for emergency management in the periods of detection and preparation.

V. Conclusions

Emergency management is becoming an important field dealing with the contingent events and disasters. The characteristics of contingent events and the complex environments make the emergency decision very difficult. The uncertain and imperfect information, the evolving structures and function principles of contingent events, make the traditional decision approach based on perfect and robust premises unsuitable for emergency decision. The immune-inspired multi-signal decision model introduces a novel model for emergency decision to consider the specific conditions and objectives of emergency management. The model is studied and a decision support framework is proposed. The study aims at a practical and important problem faced by the governments and society. The results can be referenced for emergency management system and theories. However, the research also raises some difficulties as new directions. First, the design of detector network is critical for the discovery and discrimination of contingent events. Second, the theory of multi-signal decision should be furthered to perfect the foundation. Third, the hierarchical decision process should be modeled and optimized to consider the more concrete conditions and objectives. In this study, only the holistic framework is proposed. Other topics and directions will be published in the future study.

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