The Research of a Decision-Making Model based on OODA Loop for Emergency Evacuation in City

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Abstract

In the decision-making process of city emergency evacuation, due to limited resources and time, and changing situation, it is difficult to make emergency decision accurately and efficiently. Therefore, in this paper, the city emergency evacuation decision-making model based on extended OODA loop is constructed. Through task determination and task allocation of emergency evacuation, the emergency decision-maker perceives and understands the present the situation. And the accuracy and efficiency of emergency evacuation can be improved through the planning and acting of the plan. At last, the prototype system for decision-making of emergency evacuation in city is designed and developed to validate this model.

Keywords: *emergency evacuation, decision-making model, OODA model, emergency decision*

1. Introduction

A series of emergent events, like the SARS crisis, the terrorist attacks of 9·11, 2001, the Indian Ocean tsunami disaster, 2004, the Hurricane Katrina strike, 2005, the China's 5·12 Wenchuan earthquake, 2008, the Japan's 9.0 earthquake and nuclear leak, 2011, etc., not only caused immense damage and great property loss to the world, but also influenced the stability and economic development of country. But at the same time, the frequently occurred emergencies urge research institutions of the world to carry out a lot of study on response methods and mechanisms of unexpected incidents.

As a vast territory country, China is located between the circum-Pacific seismic belt and the Himalayas seismic belt, its 23 provincial capitals and cities, and the majority of cities with a million or more population locate in the high-risk area of seismic intensity 7 above; crossing the north temperate zone, temperate zone and subtropical areas, it is often hit by typhoon, flood and drought; with complex geological structure, the southwest and mountainous areas are often struck by landslide and mudslide; meanwhile, there are many volcanic belt. In the first half of 2010, according to statistics, in China, 250 million people (times) were affected by natural disasters, among which 3,514 people died, 486 people missing, 644 million people (times) were emergently evacuated. Moreover, China enters the era of rapid growth in society and economy, with relatively increased density of population, construction, production, and wealth; but at the same time, all kinds of conflicts appear, if mismanaged, various social crises may take place.

As the important part of city emergency management, city emergency evacuation is the fast movement of people responding to large unexpected catastrophic events. The essential of it is, in limited time, to carry out the most effective emergency evacuation to the affected population, and, through fast and effective measures, to minimize the losses of the affected people, thus to achieve the optimal evacuation.

But in the process of city emergency evacuation, because of limited resources and time and changing situation, the emergency decision-maker often relies more on personal understanding, preference, knowledge, experience, judgment and creativity, rather than traditionally rational decision-making. That is to say, before making any decision, it is impossible for emergency evacuation decision-maker to take full account of all action and corresponding impact to choose the most valuable plan. At present, the emergency evacuation decision-making tends to take "extensive" directing method, therefore, it is difficult to make precise, detailed and effective emergency evacuation plan.

Therefore, focusing on professional feature of city emergency evacuation in China, the city emergency evacuation decision-making model will be constructed in the paper so as to improve city emergency evacuation management, to transform extensive directing method into

precise one, and to promote efficiency and accuracy of emergency evacuation. At the same time, as research going on, the role of computer in emergency evacuation management will come into full play, so the decision-maker can get more accurate and scientific decision-making, thus can change impulsive type of decision-making in the past, and strengthen the basic work of capacity building in city emergency management of the country.

2. Related research

2.1 Emergency evacuation model

The research of Emergency evacuation began in the 1970th of the 20th century, the initial phase of emergency evacuation achievements was less, mainly aimed at the type of incident are hurricanes and fires, including NETSIM[1] model of city traffic simulation faced hurricane and the emergency evacuation model within the building[2] and so on. In the 1980s, the emergency evacuation began development, especially after the Three Mile Island nuclear accident in 1979, the research focus of emergency evacuation also turned to the threat of nuclear power plant, traffic network evacuation model CLEAR[3] for nuclear accident and traffic simulation model NETVAC[4] has been established, other various evacuation model[5][6] have appeared, and the behavior study[7] and management study about emergency evacuation[8] has also begun. After 1990s, emergency evacuation has attracted of the world, the research of emergency evacuation within the building are developed[9][10], and the emergency evacuation of the open space has attracted researchers' attention, especially emergency evacuation for hurricane [11] . From 2000, in order to reply to the natural disasters which have occurred frequently, dozens of emergency evacuation model and simulation software have developed by research teams[12][13]. It can be applicable to many kinds of emergency environment like buildings, open space and so on, able to respond to fires, hurricanes, terrorist attacks and other emergencies, also used many kinds of modeling and simulation method based on Agent, cellular automata, network flow and so on. A simulation model of emergency response[14] based on discrete dynamic system and Agent theory has be established. And X Chen used the modeling and simulation methods based on Agent, analyzed the parallel evacuation strategies and stage evacuation strategies of city evacuation, thought evacuation strategies need to depend on the network environment and population distribution[15], Jianyong Shi discussed fire evacuation problems of public building, and established system simulation model including physical model and mathematical model for the 2008 Beijing Olympic venues [16]. Moreover, Bo Zhang modeled and simulated the family evacuation for the hurricane scene, and the result showed that the greedy Agent although will shorten the evacuation time, but do not contribute to the overall evacuation efficiency[17]. HH Naghawi researched the simulation model based on the traffic evacuation, and simulated the evacuation of New Orleans by using TRANSIMS[18]. The paper[19] established the large-scale open space evacuation model base on the random Markov model including the factors of road network, evacuation transport, traffic congestion, weather conditions. Eungho designed the BDI modeling framework for emergency evacuation decision-making [20], and Alexia designed emergency evacuation simulation framework based on Multi-Agent BDI architecture[21]. As an open source and large-scale multi-Agent traffic simulation tools, MATSim has been used for traffic simulation, emergency evacuation and other related applications in Switzerland of Zurich, Berlin and Munich of Germany, Padang of Indonesia, Toronto of Canada, Tel Aviv of Israel and other regions [22] [23].

At present, a variety of emergency evacuation models have emerged from emergency evacuation study. But these models are specific to public emergencies (such as hurricanes, fires, etc.), or only apply to certain specific area (such as buildings, expressways, etc.) or by specific scenarios (such as static building evacuation scene, the lack of dynamic data support, etc.). And they can not be applied to characteristics such as the diversified city emergency types, intensive population density, and the dynamic change of decision situation and so on. Accordingly, this paper presents a decision-making model which can be adapted to the need of emergency evacuation in city. Correspondingly, the accuracy and efficiency of emergency evacuation in city can be improved.

2.2 OODA Decision Model

Emergency evacuation decisions of decision-makers are the decision-making process under the special constraints formation, the feature of decision-making process is high risk, information uncertainty, the goal of the decision making environment is dynamic and uncertain, decision-making is nonprocedural, decision-making in line with satisfaction principle rather than optimal principle, that need decision-makers who have experience, and decision-makers have time pressure, the decision-making process is an iterative process, etc. Therefore, emergency evacuation decisions to rely more on the understanding of the

decision-makers on the current context of the emergency, situation, obtain prognosis of the future development of the event through analyze trend information, and then determine the decision and action process.

The United States Army colonel John Boyd presented Boyd control loop[24] concepts in the information warfare field, including Observe, Orient, Decide and Act. Boyd Cycle that OODA decision model obtains various state information by observing, uses fixed position to understand situation, and then makes scheme through the decision, implements the plan finally, as shown in figure 1.On this basis, according to the U.S. military theory including Network Centric Warfare and Effect Based Operations, Smith proposed the extended OODA ring decision-making model[25], and discussed the OODA decision-making process in the physical domain, information domain and cognitive domain.

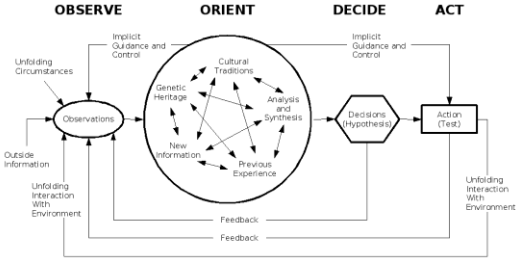

Figure 1 OODA Decision Model [26]

Aiming at the characteristics of city emergency evacuation decision-making, this paper will build the city emergency evacuation decision-making model based on OODA, realize precise command and decision of emergency evacuation.

3. City emergency evacuation decision-making model

Based on extended OODA loop decision model, the paper raises the research framework of massive open-space emergency evacuation computation model, shown in Figure 2. Involving physical domain, information domain and cognitive domain, the research starts from the real world of emergency evacuation, through perception, gains city emergency evacuation data and situation data in the real world, and gets emergency evacuation knowledge through analysis and summary. On the basis of it, the emergency decision-maker makes cognition, based upon situation data and knowledge, determines task of city emergency evacuation, then according to task and situation, allocates the task, and decides the emergency evacuation plan, and finally carries out the plan to realize accurate decision and command on massive open-space emergency evacuation.

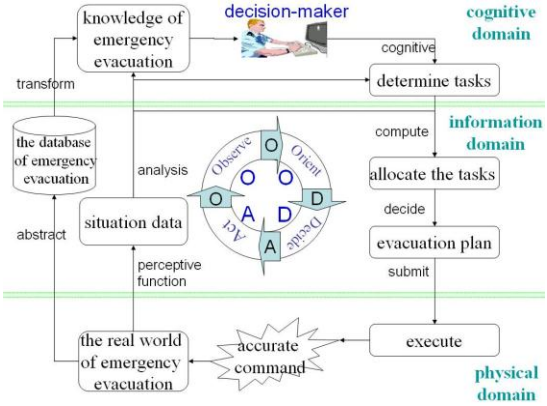

Figure 2 A decision-making model for emergency evacuation in city

In the OODA-based city emergency evacuation decision model, Observation means perceiving situation data through various sensors, Orientation means that decision-maker determines emergency evacuation task according to situation data, Decision means allocating the task and generating emergency evacuation plan, and Action means evacuating according to the plan, then repeatedly sensing emergency evacuation situation and making orientation and decision in the execution of the plan, that is the loop of replanning and performance according to the situation. The paper puts emphasis on the Orientation and Decision of the city emergency evacuation decision model.

3.1 Orient

In the emergency evacuation decision-making model, according to the emergency situation and emergency evacuation of knowledge, the orientation process and decision makers need to identify specific, feasible emergency evacuation missions. The paper adopts BDIP Agent [27] to achieve oriented process, namely, identifies emergency evacuation task.

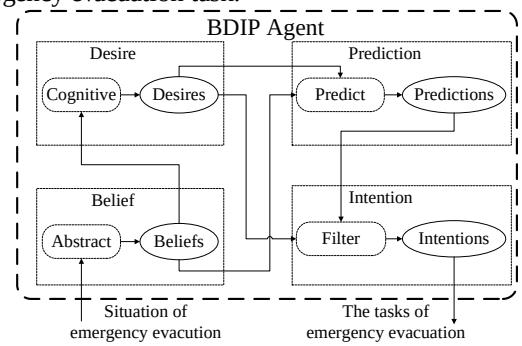

Figure 3 Oriented process based on the BDIP agent city emergency evacuation decision-making model

The oriented processes based on the BDIP Agent city emergency evacuation decision-making model can be seen in Figure 3, Agent can get external situation information through sensors, beliefs can be formed through abstract, desires can be formed after perceiving, then the model calculate on the basis of faith and desire, get the results, obtain the intention of the Agent after filtering, and output the evacuation tasks finally.

The directed algorithm of emergency evacuation decision model is described as follows: supposing B_0 as the initial belief set, D_0 as the initial desire set, P_0 as the initial prediction set, I_0 as the initial intention set. Get the current situation through the Get(G); update the belief set B according to the current situations and beliefs; continue to update the desire set D according to current beliefs and the desires; then according to the current beliefs, desires and the current predictions to predict, get the prediction of P; finally filter current desires set according to the current beliefs and predictions, as intention I; according to the current beliefs and intentions to generate the task set Π; choose one task π to execute. Execute the action of the plan for loop, after performing an action, update the beliefs, desires, intentions, predictions, adjust task π, when meet one of three conditions, namely the task of π is empty, executed, unable to perform, then jump out of loop. In the process of implementation, such as the task cannot be performed, then BDIP Agent will raise the issue to the decision makers. The algorithm is represented as follows.

Input: initial belief B_0, initial desire D_0, initial prediction P_0, initial intention I_0
Output: task π

```
B:=B0;
D:=D0;
P:=P0;
I:=I0;
while true do
  g:=Get(G);
  B:= Brf(B, g);
  D:= Option (B, D);
  P:=Com(B, D, P);
  I:=Filter(B,D,P,I);
  Π:=Planning(B,P,I);
  π:=Decision(Π);
  while not (empty (π) or succeeded(I,B) or impossible(I,B) ) do
    α:=hd(π);
    Execute α;
    π:=tail(π);
    g:=Get(G);
    B:= Brf(B, g);
    D:=Options(B,D);
    P:=Com(B,D,P);
    I:=Filter(B,D,P,I);
    Π:=Update(B,P,I,Π);
    π:=Decision(Π);
  end-while
  if impossible (I,B), post the problem to others
  end-if
end-while
```

3.2 Decision-making

The decision-making process of emergency evacuation decision-making model is made up two parts which are allocating tasks and planning, as shown in Figure 2. Allocating tasks are responsible for allocating the appropriate distribution of the emergency evacuation to the appropriate Agent, in order to take full use of the system's resources, improve the operational efficiency of the system. Planning process is based on the reference of emergency evacuation plans, draw up emergency evacuation plan according to the task allocation list.

3.2.1 Task allocation

In the process of emergency evacuation, there are a lot of Agents and a variety of tasks, each Agent has its own capacity constraints and limited resources, such as ambulance is suitable for performing the task of medical treatment and evacuation vehicle is responsible for the transportation of evacuees. The allocations of Emergency evacuation tasks are finding which scheme is match for reasonable tasks and Agents, to improve the effectiveness of emergency evacuation system.

The calculation process of emergency evacuation task allocation is shown in Figure 4, the BDIP Agent determines whether there is need to perform the task through the acquisition of the real-time data, if there is no idle Agent, then decision makers will distribute tasks and classify the Agent, each category of Agent will be combined respectively, the task distribution feedback efficiency will be calculated, take the maximum allocation of the performance of each type of combination, develop the initial plan, decision maker can adjust formation of preliminary scheme, to form evacuation plans.

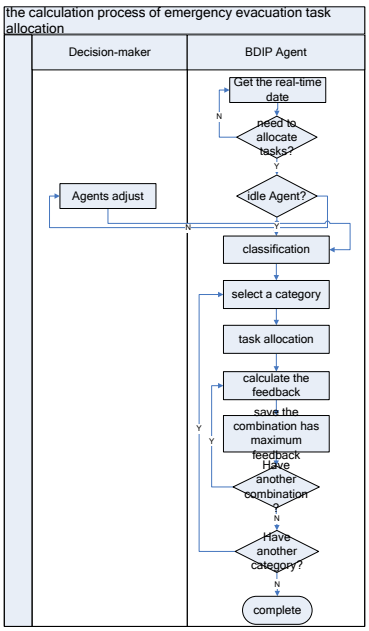

Figure 4 The calculation process of emergency evacuation task allocation

The formalized expression of the emergency evacuation task allocation based on the GAP model can handle the multi-agent task allocation problem when resources are limited and maximize the system expected feedback, it can be described as follows:

(1) Task set J in the Emergency evacuation process need to be assigned to Agent set I.

(2) Any Agent $i \in I$ has constraints of emergency resource r_i (assumptions for individual resources)

(3) When Agent i performing the task $j \in J$, emergency evacuation mission j is consuming c_{ij} unit's emergency resource of Agent i.

(4) Agent i has the ability value $k_{ij}\left(0 \le k_{ij} \le 1\right)$ to perform emergency evacuation mission j.

(5) In emergency evacuation task allocation matrix A, when the value of matrix element a_{ij} is 1 indicates that the emergency evacuation missions j will be assigned to the Agent i, when its value is 0 indicates that the emergency evacuation missions j will not be assigned to the Agent i.

The optimal solution of emergency evacuation task allocation problem is providing maximum feedback of distribution matrix A* for emergency evacuation system, the calculation formula is:

$$A^* = \arg\max_{A'} \sum_{i \in I} \sum_{j \in J} k_{ij} \times a'_{ij} \quad (1)$$

Constraint condition is:

$$\forall i \in I, \sum_{j \in J} c_{ij} \times a_{ij} \le r_i$$

$$\forall j \in J, \sum_{i \in I} a_{ij} \le 1$$

The formula $\forall i \in I, \sum_{j \in J} c_{ij} \times a_{ij} \le r_i$ represents distribution Matrix A * must be taken into account the Agent resource constraints, $\forall j \in J, \sum_{i \in I} a_{ij} \le 1$ represents each task is assigned to one Agent at most.

3.2.2 Planning

Emergency evacuation plan is the process that the emergency evacuation can quickly make timely and accurate emergency response when emergency occurs. Based on the emergency plan, planning is according to the nature, size, type of public emergencies and with reference to the corresponding emergency evacuation plan. Emergency evacuation decision-making refers to the process of making plan with reference to the emergency evacuation plan, on the basis of the emergency evacuation task allocation and calculation, as shown in figure 5.

Figure 5 The planning process of emergency evacuation

The steps of emergency evacuation planning are as follows:

Step 1, in the list of task allocation, if there is untreated task, according to the task as well as assigned to the emergency rescue Agent, find the corresponding emergency plans, if there is no untreated task, then jump to step 4.

Step 2, according to implemented action of the emergency plan and all kinds of constraints, develop the plan for performing assigned tasks of the rescue Agent.

Step 3, store the plan and jump to step 1.

Step 4, according to the collaborative relationship among tasks, make disposal plan of single Agent in pairs.

Step 5, formulate emergency evacuation plan.

In order to standardize the representation of the emergency evacuation plan, the plan can be described according to the following definitions.

Definition 1 emergency evacuation plan can be expressed as $Plan =< planname, agents, constrainsts >$

In the expression, *planname* indicates the name of emergency evacuation plan, such as emergency evacuation plan of chlorine leakage accident; *agents* indicates Agent collection of emergency evacuation plan; *constrainsts* indicates various constraints in the emergency evacuation plan, including the constraints of the order between Agent internal and Multi-Agent, front constraints, rear constraints, etc.

Definition 2 Agent of emergency evacuation plan can be expressed as $Agent =< agentname, tasks, inconstrainsts >$

In the expression, *agentname* indicates the name of the principal in the emergency evacuation plan, such as medical teams, fire brigade etc. ; *tasks* indicates a collection of tasks in emergency evacuation plan that Agent needs to perform ; *inconstrainsts* indicates the set of constrained relations between Agent internal tasks, including sequential constrained relations, parallel constrained relationship, selective constrained relations and circular constrained relations .

Definition 3 tasks of emergency evacuation plan can be expressed as
$task =< taskname, preconditions, postconditions, resource >$

In the expression, *taskname* indicates the name of the task, such as medical treatment ; *preconditions* indicates collection of the task of pre-conditions, such as after evacuation vehicles arrived at the concentrate sites, organize evacuees boarding ; *postconditions* indicates collection of the task of post condition, indicates the possible effects of task, namely leads to the change of state after task execution; *resource* indicates resources of task execution, such as transport vehicles, etc.

Definition 4 constraints of emergency evacuation plan can be expressed as
$constrainsts =< preconstrainst, postconstrainst, outconstrainst >$

In the expression, *preconstrainst* indicates pre-constraint set of the emergency evacuation plan, namely execution conditions of the plan ; *postconstrainst* indicates rear constraints set of emergency evacuation plan, namely to judge whether the plan is executed according to this constraint ; *outconstrainst* indicates the collaborative relationship among agents, including sequential collaborative relationship *orderconstrainst* , initial parallel collaborative relationship *beginandconstrainst* , end of parallel collaborative relationship *endandconstrainst* , initial selective collaborative relationship *beginorconstrainst* , end of selective collaborative relationship *endorconstrainst* .

4. Application

On the basis of the research, the prototype assistant decision-making system of city emergency evacuation is designed and developed. The construction of the prototype system can test the effectiveness and feasibility of city emergency evacuation decision-making model, and do some exploratory work to enhance the efficiency of city emergency evacuation management.

The framework of assistant decision-making system can be seen in Figure 6. Through data supporting platform, like video conference, visual telephony, computer network, GPS, monitoring equipment, satellite image transmission, and wireless communication network etc., and from all kinds of data sensor, connected emergency platform, ministries and special headquarters, the system can get various types of data that emergency evacuation required, and store the data into emergency evacuation resources center, including situation database (situation data, e.g. event status, population distribution, traffic flow, etc.) and information resources database (information, e.g. basic geography, means of transportation, emergency experts, etc.). With the support of emergency evacuation data, the application function of assistant decision-making system can be realized, including emergency scene plotting, visualized emergency evacuation, emergency scene generation, emergency evacuation planning, emergency evacuation plan deduction and plan evaluation etc.

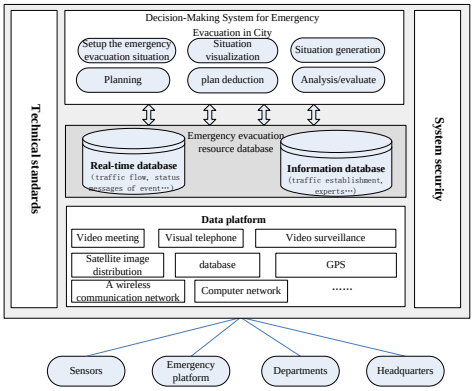

Figure 6 The Framework of Decision-Making System for Emergency Evacuation in City

Based on the research of city emergency evacuation decision-making model, the function of the prototype of decision-making system can be realized (shown in Figure 7 and Figure 8), including:

- ✧ Developed electronic sand table function of assistant decision-making of emergency evacuation, thus basic functions, like map zooming and map measuring etc., and other functions, like all kinds of geographic information query and roaming etc., can be realized.
- ✧ Setting attribute and icon of scene information, like emergency resource, the subject and emergencies etc., and then plotting them in emergency evacuation network, thus emergency scene can be constructed .
- ✧ In the emergency evacuation scene, through getting all kinds of external real-time and situation data, emergency evacuation task can be determined.
- ✧ According to generated emergency evacuation task, and based on obtained situation data, reasonable task allocation can be carried out, and formalized emergency evacuation plan can be formed.
- ✧ Plan deduction based on the final emergency evacuation plan, and storing all kinds of data in emergency evacuation simulation, thus decision-maker can get better decision support.

Figure 7 Setup the emergency evacuation situation

Figure 8 Demonstration of plan deduction

5. Conclusion

In this paper, the decision-making model based on OODA for emergency evacuation in city is constructed. Firstly, the paper designed the oriented process of the emergency evacuation decision-making model by using the BDIP Agent model. And the corresponding orientation algorithm is given. Secondly, the task allocation model of emergency evacuation is established in decision-making process. Furthermore, the formalized representation and planning method of emergency evacuation plan are raised. Finally, the decision-making prototype system for emergency evacuation in city is designed and developed to validate the effectiveness and feasibility of the decision-making model.

Current work focuses on the individual decision-making model for emergency evacuation in city, and addressing issues such as the shared mental decision-making model for emergency evacuation in city.

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