Modeling and Analysis of Emergency Response Plan Based on Network Diagram

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Abstract. Modeling of emergency response plan is the basis for reducing the harm and adverse effects of sudden disasters on society. Multi-entity (unit) participate in emergency response plan has high synergy in workers and entities, strong logical relationship, etc. In this paper, the natural disaster emergency response plan is the research object, and the emergency rescue mission is directive, and rescue time is the main line, and model is builded by using the network diagram. This method aims to express all kinds of emergency response plans more flexibly and accurately, and the complex relationship between internal working rooms and the expression of structural networks. At the same time, this paper establishes a task which completion probability model to comprehensively evaluate emergency response capabilities based on time. The emergency response network diagram established in this paper has the characteristics of the network and can be combined with complex network theory for in-depth research.

1. Introduction
Natural disasters such as earthquakes, typhoons, tsunamis, floods, snowstorms and droughts have been frequent in the world. This is a test of people's emergency response capacity in the event of natural accident. When natural disasters happen, needs of the affected areas for various types of relief supplies (tents, food, water and medical supplies, etc.) and rescue workers are the most urgent. For different situations of natural accident, state and government must implement rational and efficient rescue operations in accordance with pre-established emergency response plan. Therefore, higher requirements are put forward for the rationality and flexibility of the emergency response plan. As governments and researchers pay more attention to emergencies, emergency management is rapidly developing as a new discipline [1-3]. The emergency management of emergencies mainly includes four stages: disaster reduction, disaster preparedness, emergency response and disaster recovery [4-6]. Among them, the emergency response is the core method, which requires the active participation of multiple related entities and the coordination of each other to complete the emergency response. Multi-entity participation refers to the participation of multiple entities based on the analysis and processing of current emergency environment information, according to the comprehensive analysis of organizational relations, entity functions and expert opinions, the current emergency rescue mission objectives are determined. And through communication and coordination of mutual relations, relevant departments formulate concrete and feasible emergency action plans, and finally complete emergency rescue missions based on effective implementation of these programs [7].
In the emergency response plan, the number of entities involved is large and the work is complicated, and the time correlation and spatial correlation between each work room are strong. Due to the time-varying nature of emergencies, the evolution of behaviors is extremely complex, and because of lacking disposal experience, emergency action plan is difficult to obtain through models based on a large number of mathematical statistics [7]. Therefore, a flexible mathematical model is needed to fully express the emergency response plan.

Based on the previous researches on emergency response plan, network diagram modeling methods is used, and the internal aggregation relationship between work and work is refined according to the overall task requirements of emergency rescue. Mining The joint point is found between the emergency response plan and the network diagram, that is taking the time as the main line, and assigning each collaborative entity (unit) rationally, and establishing a work collaboration model. Because the emergency rescue mission requires higher time urgency and the necessity of completing the task, therefore, this paper uses the time-based task completion probability to evaluate the emergency response capability of the emergency response plan.

2. Modeling of Emergency response network diagram

2.1. Composition of emergency response network diagram

According to the characteristics and requirements of the emergency response plan, the composition of the emergency response network diagram is divided into two parts: basic composition and typical structure.

2.1.1. Basic symbol of emergency response network diagram

(1) Emergency response directed edge: it refers to the work in the emergency response network diagram, which is divided into the following two categories.

1) Emergency response directed real edge: it refers to a specific work that requires resources and time in the emergency response plan. In the emergency response network diagram, it is represented by a real arrow, tail of the real arrow indicates the beginning of the work, and arrow of the real arrow indicates the end of the work. the name or code of the job is marked above the real arrow and the time of execution of the job is marked below. As shown in figure 1.

![Figure 1. Emergency response directed real edge.](image)

2) Emergency response directed virtual edge: it refers to a artificial virtual work, which has no name or code, has no execution time, and does not consume resources. It is represented by a virtual arrow in the emergency response network diagram. It only acts as a connection in the emergency response network diagram. Generally, it is connected with symbolic models such as transformation decisions, logic gates, data and annotations, etc. As shown in figure 2.

![Figure 2. Emergency response directed virtual edge.](image)

(2) Emergency response node: it refers to the connection point between edges of the emergency response, which is divided into the emergency response plan status node and the emergency response plan logical node.
1) State-node of emergency response: it refers to the transient state of work in the emergency response plan. It serves as a connecting link between the preceding and the following, and it does not consume resources and time, in the emergency response network diagram, it is represented by a circle, and the circle is numbered to represent the order of the working state. As shown in figure 3.

![Figure 3. State-node of emergency response.](image)

Generally, when we write the serial number, the network diagram for emergency response has been basically completed, so we can write it from left to right in order. So a job can be represented not only by the arrow but also by the two nodes connected to the shaft.

2) Logical node of emergency response: it refers to the node of the behavioral state in the emergency response plan, which is divided into the following categories.

a. Switch Node: it refers to the structure of conditional judgment and selective output in the emergency response plan. In the emergency response network diagram, it is represented by the horizontal diamond, the input is the left or upper end of the diamond, and the output is the right and lower end of the diamond. This structure is connected by using a virtual arrow. As shown in figure 4.

![Figure 4. Switch Node.](image)

b. Logic gate: it refers to the logical polymerized structure in the emergency response plan. The input has two forms: ‘AND-gate’ and ‘OR-gate’. Using a virtual arrow to connect this structure. There are two types of deterministic and probabilistic outputs. The deterministic output is represented by a semicircle. Only one job can be connected with the deterministic output, and the probability of execution of the work is 1. The probabilistic output is represented by a triangle, which can be connected to multiple jobs, and these jobs are executed with a probability of between 0 and 1, and all possibilities add up to 1. As follows.

AND-gate with deterministic output: [\( \and \) ]; AND-gate with probabilistic output: [\( \and \) ]; OR-gate with deterministic output: [\( \or \) ]; OR-gate with probabilistic output: [\( \or \) ].

c. Loop body: it refers to a simplified expression of one or more tasks that need to be performed more than once in a certain section of the emergency response plan. It is represented by a rectangle in the emergency response network diagram, and a virtual arrow is used to connect with this structure. The relevant description should be indicated in the rectangle. As shown in figure 5.

![Figure 5. Loop body.](image)

d. Preparation: it refers to an entity of emergency response in the emergency response plan that is ready to perform related work, and it is waiting for the command. It is represented by a hexagon in the
emergency response network diagram. The input is the left end of the hexagon, which is connected by a real arrow; the output is the right end of the hexagon, which is connected by a virtual arrow. As shown in figure 6.

![Emergency Response Network Diagram](image)

**Figure 6.** Preparation.

In the emergency response network diagram, the last end node has no output. However, the preparation node does not indicate the end point of the emergency response plan, but it is inactive. The structural of preparation can reflect the aggregation of the emergency response plan entities intuitively.

e. Symbol of annotation: it refers to the content that needs to be annotated in the emergency response plan. It only has the input end, and the input end is connected with a virtual arrow, and the annotated content is filled in the right parenthesis. As shown in figure 7.

![Symbol of Annotation](image)

**Figure 7.** Symbol of annotation.

2.1.2. **Logical structure of emergency response network diagram**

(1) Serial structure: In the serial structure, works are executed in chronological order. For example, these works (a1, a2, a3, b1, b2, and b3) are executed in the following order. As shown in figure 8.

![Serial Structure](image)

**Figure 8.** Serial structure.

(2) Parallel structure: In the parallel structure, multiple works can be executed simultaneously in the same time period, and the work in the parallel structure is also called parallel work. As shown in figure 9.

![Parallel Structure](image)

**Figure 9.** Parallel structure.
(3) Conditional structure: In the course of emergency response planning, the judgment of the condition often happens, and the direction of advancement of the work depends on whether the situation is met. The conditional structure has the following categories.

a. The conditional structure does not affect the work advancement. As shown in figure 10.

b. The conditional structure of the alternative scheme is adopted, as shown in the following figure, A1 is executed when the condition is satisfied, and the alternative scheme A2 is executed if the condition is not satisfied. As shown in figure 11.

c. Loop structure: In the course of emergency response planning, the loop body model established in the previous article often appears, but the loop body cannot be an “infinite loop”, which will never stop. It is necessary to terminate the loop under certain conditions, so we combine the loop body and the conditional structure to form a loop structure to solve the “infinite loop” problem. As shown in figure 12.

d. Cross structure: Parallel arrows should be used in the emergency response plan to reduce the crossover of the arrows. When the crossover is unavoidable, the “dark bridge” approach should be adopted. As shown in figure 13.
Modeling emergency response network diagram

Modeling emergency response plan by network diagram is a graphical form, that can represent the logical aggregation relations between entities and works in the emergency response plan graphically. A network diagram consists of directed arrows and nodes, that represent a directed, ordered mesh line of the emergency response plan workflow.

The steps of modeling emergency response network diagram: The first is to decompose the entire emergency rescue task into multiple tasks based on the emergency environment information, according to the organizational relationship, entity functions and expert opinions, and a work logic table can be established. Then, according to the logical relationship from the work logic table, the work is correctly connected by using the forward method.

3. Evaluation of Emergency response capability

In the emergency response plan, due to the urgency of time and the necessity of completing the work, this paper uses the time-based task completion probability to evaluate the emergency response capability of different emergency plans. The mission completion probability is the probability of completing the emergency response target. In other words, the probability of the emergency response plan target can be completed within the specified time.

Works' time in the emergency response plan is a non-deterministic problem, so three-time-estimation is used here. We define \( a \) is the time of work completed successfully (the shortest time); and \( b \) is the time of work completed under unfavorable conditions (the longest time); and \( c \) is the time of work completed under historical experience and expert opinions (possible duration). The formula for calculating the time variance of the work is as follows.

\[
\sigma_e^2 = \left( \frac{b-a}{6} \right)^2
\]  

Using the “central limit theorem” to calculate the probability of completion of the task, the completion time of each work in the emergency response plan is equal to the positive distribution approximately, a probability factor \( z \) is introduced, probability \( P = P(z) \).

\[
z = \frac{t_L - t_E}{\sigma_{cp}}
\]

\[
\sigma_{cp} = \sqrt{\sum \sigma_e^2}
\]

In the formula, \( t_L \) is the latest completion time of the end node in the emergency response network diagram, and it is also the latest completion time of the emergency response plan. \( t_E \) is the earliest start time of the end node in the emergency response network diagram; \( t_L - t_E \) is the time difference of the nodes; \( \sigma_e^2 \) is the variance of the work on the critical line in the entire emergency response network diagram. \( \sigma_{cp} \) is the standard deviation.

The higher probability of completion of the task, the higher probability of the emergency response plan target can be completed within the specified time, the more likely it is to achieve the desired result, the higher coordination between the works, the more enforceable of the solution, the emergency rescue capability is stronger.

4. The instance

In an emergency response plan action, the participating emergency entities have X1, X2, X3, X4, X5, and X6. The workflow is: start; X1, X2 and X4 perform work Y1; X1, X2 and X4 perform work Y2; X1, X2 and X4 perform work Y3; X2, X3 and X5 perform work Y4; X6 performs work Y5; X1, X5
And X6 performs work Y6; ends. The emergency response plan must be completed within 20 hours. The working logic table is shown in Table 1.

Table 1. The working logic.

| Name of task | Perform entity | Sequence work before |
|--------------|----------------|----------------------|
| Y1           | X1,X2,X4       | -                    |
| Y2           | X1,X2,X4       | Y1                   |
| Y3           | X1,X2,X4       | Y2                   |
| Y4           | X2,X3,X5       | Y3                   |
| Y5           | X6             | Y4                   |
| Y6           | X1,X5          | Y3,Y5                |

The works’ label and time are showed in the table 2.

Table 2. The works’ label and time.

| Name of task | a (hours) | b (hours) | c (hours) |
|--------------|-----------|-----------|-----------|
| Y1           | 4         | 8         | 5         |
| Y2           | 2         | 5         | 5         |
| Y3           | 6         | 14        | 7         |
| Y4           | 6         | 10        | 7         |
| Y5           | 3         | 5         | 4         |
| Y6           | 1         | 4         | 3         |

The emergency response plan is modeled by network diagram as shown in the following figure 14.
Figure 14. Emergency response network diagram.

Through the above emergency response network diagram, the key lines can be found as 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13, and 14. The standard deviation on the critical line is as follows.
\[ \sigma_{cp} = \sqrt{\frac{(8-4)^2}{6} + \frac{(5-2)^2}{6} + \frac{(14-6)^2}{6} + \frac{(10-6)^2}{6} + \frac{(4-1)^2}{6}} \approx 3.2 \]  
\[ z = \frac{t_{c} - t_{e}}{\sigma_{cp}} = \frac{20-19}{\sqrt{3.2}} = 0.56 \]  

\( P = 0.71 \) can be obtained by checking the normal distribution table. The probability of the emergency response plan target is completed within 20 hours is 71%.

### 5. Conclusion

For emergency response plans, this modeling approach through network diagram is simpler, more intuitive, and easier to understand than other methods, and those modeling structures are richer and more powerful, and the correct logical structure can describe the coordination and aggregation between the internal elements of the emergency response plan accurately. This method can expression a variety of emergency response scenarios flexibly, and it can be changed according to timeliness, so, it applies more broadly. The task completion probability is used to evaluate the emergency capability to meet the timeliness requirements of the emergency response plan objectives.

The model of emergency response plan based on network diagram provides a macro perspective for the analysis of emergency response plan capability, which is more practical and expansive. The emergency response network diagram can reflect the complex coordination and aggregation relationship within the emergency response plan visually, and it has certain complex network properties. Next, we will analyze from the perspective of complex network theory as the next research direction.

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