Research on the reliability model of emergency dispatch considering the advance state of time factor

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Abstract. With the frequent occurrence of major emergencies in recent years, the guarantee problem of emergency material dispatching has gradually come to the fore. In this paper, the reliability of the emergency material dispatching system is studied based on the analysis of the dispatching process and influencing factors, and the network model of system reliability is constructed by combining the GO method and Bayesian network as modelling tools. Bayesian forward and backward inference is used for fault inference to find out the system's weak points. On this basis, the model is extended to the sensitivity study of system reliability. It is found that the material dispatching subsystem has the highest failure rate, in which material transportation time, emergency vehicle waiting time, implementation plan development time, satisfaction with the quantity of material at the affected point and agility of the dispatching information system are the main influencing factors.

Keywords: system reliability; emergency material dispatch; GO-Bayesian synthesis

1 Introduction

In recent years, various large-scale emergencies have become more and more frequent, and the dispatching of emergency materials for emergencies has received increasing attention. However, dispatching materials under emergency conditions face a complex environment with inaccurate demand information, differences in demand urgency and dynamic and variable traffic and transportation networks, which further increase the difficulty of dispatching emergency materials. Therefore, the research on emergency material dispatching should also take into account system stability and reliability.

Some scholars in the existing research have started from the perspective of system reliability, and have studied the reliability of the smooth flow of the collector road [1], the reliability of the multi-factor urban emergency firefighting system [2-3], and the reliability evaluation considering the workflow structure [4]. In terms of research methods, the system reliability was studied using Petri net isomorphic Markov chain [5], GO method with trapezoidal fuzzy number theory [6], and positive and negative inference of Bayesian network [7]. Most of the above studies are on the commonality of various emergency material dispatching or on a single system and lack research on the

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operational reliability of the whole system and identification of the weak links after a system failure. Most of the studies on the dispatching of emergency supplies are based on the condition that the emergency supplies meet the full demand, and most of the studies on the prediction of emergency supplies are conducted with a single data source, lacking the fusion analysis of multiple types of correlated data, which is not consistent with the actual situation of emergency supplies gap in major emergencies. Therefore, this paper integrates multiple factors affecting system failure and introduces an advanced working state in time reliability index, and uses the GO-Bayesian method to conduct reliability analysis and sensitivity analysis of the emergency material dispatching system to find out the weak points of the system and verify them with the traditional research comparison analysis.

2 GO-Bayesian synthesis method

The GO method is used for reliability assessment under the assumption that each unit is independent of each other for quantitative analysis, while the realistic emergency material dispatch system units have complex correlations with each other. Therefore, it is necessary to simplify the operation process of GO method by adopting a new inference method (the analysis flow is shown in Figure 1). The joint probability distribution of all variable nodes is derived from the node calculation of Bayesian network as:

$$P(v_1, v_2, \dots v_n) = \prod_{i=1}^{n} P(v_i \mid U_{v_i})$$

In turn, the direct causal relationship between parent and child nodes and the conditional probability table (CPT) are derived, and then the fault injection is performed for specific nodes in the constructed GO-Bayesian network model, and the posterior probability distribution of each node in the network is calculated by using the principle of Bayesian backward inference as：

$$P(O_i \mid F_j) = P(O_i)P(F_j \mid O_i) \Big/ \sum_{i\in\|O\|} P(O_i)P(F_j \mid O_i)$$

For the directed edge $T_i = (V_i, V_j)$, V_i is called the parent node of V_j, V_j is called the child node of V_i, and U_{v_i} denotes the set of parent nodes of V_i; O_i denotes the state of the observed nodes i; F_j denotes the state of the faulty nodes j; $\|O\|$ and denotes the number of observed nodes.

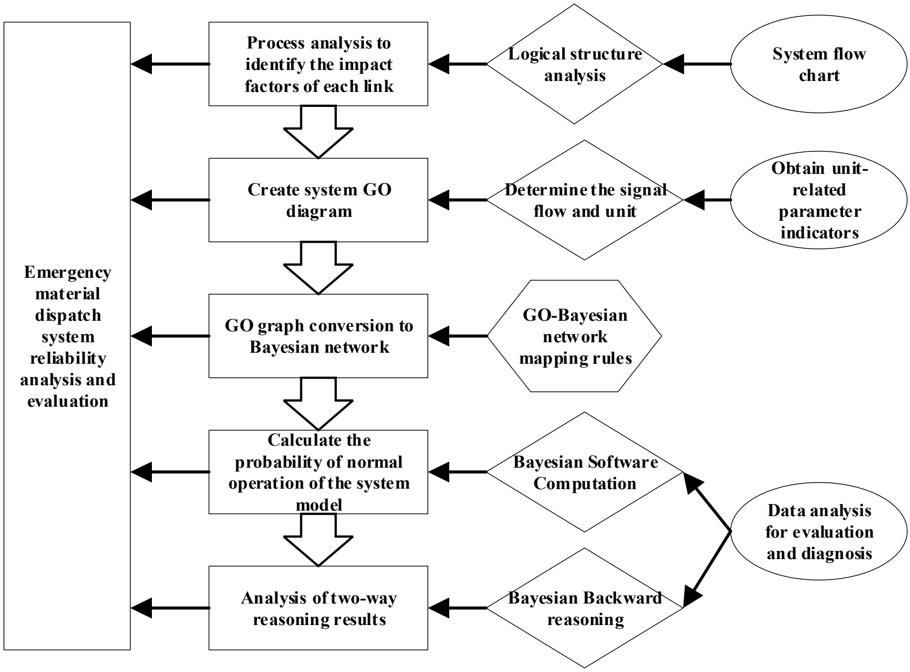

Fig. 1. Flow chart of GO-Bayesian method [Owner-draw]

3 Emergency material dispatch system reliability analysis

3.1 Emergency Material Dispatch System GO Model

Analysis of factors influencing emergency material dispatch.

. Most existing research is based on single reliability indexes, such as service reliability, quality reliability, time reliability, etc. for emergency systems. However, it is not reason enough for emergency management in real situations to analyze the reliability of emergency material dispatching systems considering only a single reliability index. Based on the previous research, the emergency management process nodes are divided into three subsystems: material preparation(P), material distribution(I), and information management (E), and the requirements of the emergency material dispatch system in terms of time, cost, satisfaction and agility are considered comprehensively, and the factors affecting the operation of the subsystems at each stage are listed. Preparation stage: time to determine demand information (P_{T1}), time to time to obtain information on material potential (P_{T2}), time to raise material (P_{T3}), cost to obtain potential information (P_{C1}), cost to develop plan (P_{C2}), cost to raise material (P_{C3}), cost to supervise and manage (P_{C4}), way to manage material dispatch preparation (P_{A1}), and management information (P_{A2}); implementation phase: time to develop implementation plan (I_{T1}), waiting time for emergency vehicles (I_{T2}), material loading and unloading time (I_{T3}), material transportation time (I_{T4}), material acquisition cost (I_{C1}), material transportation cost (I_{C2}), external cost of material dispatching (I_{C3}), satisfaction with the quality of emergency materials (I_{S1}), satisfaction with the quantity of emergency materials (I_{S2}), satisfaction with the emergency response time at the affected site (I_{S3}), agility of dispatch information system (I_{A1}), agility of dispatching methods (I_{A2}), agility of personnel adaptability (I_{A3}); evaluation phase: time for data transmission and analysis (E_{T1}), time for smooth communication of feedback information (E_{T2}), agility of real-time monitoring of dispatching process (E_{A1}), agility of guarantee mechanism (E_{A2}).

Establishing a model of emergency material dispatching system considering the time-advance condition.

. The influence factors of the subsystem are used as the system input signals, and each subsystem is converted into the GO model of the emergency material dispatching system [8] according to the GO method operator rules, where the subsystems are connected with the influence factors through signal flow, and all subsystems are fail-safe, normal working dimorphic components. Each subsystem's influence factor is connected to each other through and gate, and when any one influence factor fails, the whole subsystem requires fault repair. The material preparation subsystem and the material dispatch subsystem are connected through M take K gates, which are represented by 4 take 2 gates in this paper, i.e., there are 4 input signals, then at least 2 material preparation subsystems work normally as output when the material dispatch subsystem can operate normally, otherwise, the material dispatch subsystem is in a fault state and waits for enough materials to resume normal dispatch work. Meanwhile, according to the classification of the influencing factors, most of the existing studies take 2 states of the fault and normal the for time reliability index, but the actual dispatching process generally has 3 cases of advance, normal and delay due to different traffic smoothness states. This paper considers the traffic state situation, the time reliability index takes 3 states of advance, normal and fault, and other costs, satisfaction and sensitivity reliability-related indexes take 2 states of the fault and normal to establish the GO model of emergency material dispatching system, as shown in Figure 2.

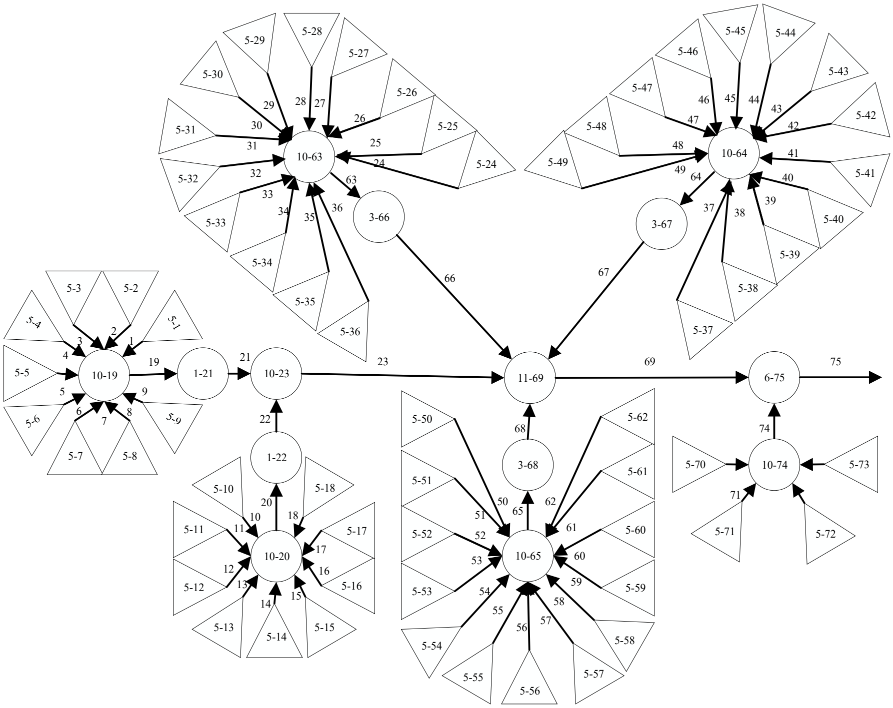

Fig. 2. GO diagram of emergency material dispatching system[Owner-draw]

The triangle in the above figure represents the signal generator, the number before the line in the circle represents the type code of different operators, and the number after the line represents the sequence number in the emergency material dispatching system, and the specific meaning is shown in Table 1.

Table 1. Factors affecting the reliability of system[Owner-draw]

Operator number	Operator type number	Unit name
1-18/24-62/70-73	5	Influencing factors of each subsystem
19-20/23/63-65/74	10	with doors
21-22	1	Material Preparation Subsystem
66-68	3	Material distribution subsystem
69	11	4 take 2 doors
75	6	Information Management Subsystem

3.2 Bayesian Network Model for Emergency Material Dispatch System

Mapping conversion of GO operators.

. The operator types of GO diagram of emergency material dispatching system include class 1, 3, 5, 6, 10 and 11. Class 1 operators are used to simulate material preparation subsystem, which is a two-state unit with only two states of normal operation and failure; class 3 operators are used to simulate material dispatching subsystem, which is different from class 1 operators in that the advance state is added to the operator state itself; take class 3 operators as an example According to the mapping conversion rules, the operator 3-66, which introduces the advance state, is Bayesian transformed and the node CPT is obtained; the class 5 operator, which has no input signals and the signals are independent of each other, is used to simulate the influence factors of different subsystems; according to the mapping conversion rules, the operator 5-1 is directly mapped to the Bayesian network root node; the class 6 operator is used to simulate the information management subsystem, which is a unit with only two signal inputs for normal output; Class 11 operators correspond to M take K logic gates, and Class 10 operators ---- with gates, which are actually special cases of Class 11 operators, which are two types of virtual operators used to simulate the logic operators of multiple input and output signal logic relationships in the system, and in this paper, the system takes Class 11 operators as an example, and according to the mapping conversion rules The Bayesian network conversion of this class of operators is illustrated with a 4-take 2 gate and the node CPT is obtained.

Bayesian network mapping for GO method.

. When using the GO-Bayesian method for system reliability analysis, the GO graph needs to be converted into a Bayesian network according to the GO method's Bayesian network mapping rules, and the GO's specific Bayesian network mapping process method is shown in Figure 3.

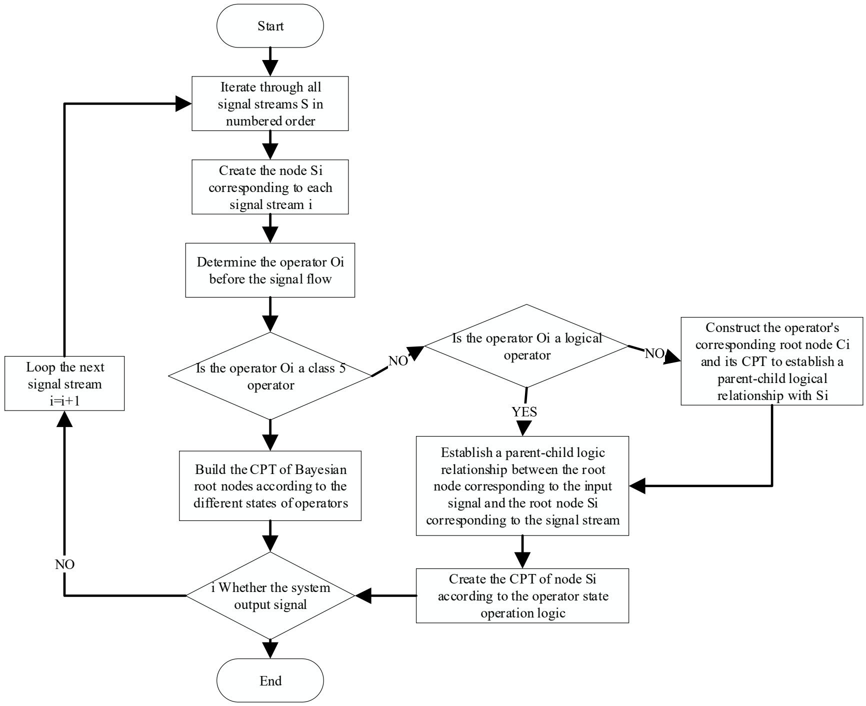

Fig. 3. Flow chart of Bayesian network mapping algorithm for GO model[Owner-draw]

Building a Bayesian Network for Emergency Material Dispatch System. . According to the GO operator mapping algorithm flow given in the previous section, the GO diagram combined with the emergency material dispatching system first maps all signal streams into corresponding nodes and connects them with arrows in the original direction, and maps other functional operators except the fifth category of operators into nodes and points them to the corresponding signal stream nodes with arrows to obtain the Bayesian network diagram, and uses S_i to indicate the signal streams in the GO diagram number i corresponding Bayesian network node, C_i denotes the Bayesian network root node corresponding to the j functional operator, all non-time influencing factor nodes are set to two states of fault maintenance and normal operation, and time influencing factor nodes are set to three states of advance, normal and fault and two states of fault and normal operation, respectively, for comparison and analysis.

4 Reliability calculation and analysis

4.1 Reliability calculation and fault diagnosis

When using the Bayesian forward and backward inference algorithm for reliability assessment and fault diagnosis, the number 0 is used to denote the advanced dance state, the number 1 to denote the normal state, and the number 2 to denote the fault state, and P denotes the probability in each state. In addition to the required prior probabilities in Table 2, the state distribution probabilities of each sub-node are also required. The probability distribution of each node is not represented in the Bayesian network diagram, and the state distribution probabilities of each node can be obtained according to the given GO operator model mapping rules.

Table 2. Bayesian network node probability distribution[Owner-draw]

Unit name	Operators	Root Node	P(0)	P(1)	P(2)
P_{T1}, P_{T2}, P_{T3}	5-1/5-10	S_1 /S_{10}	0.2068	0.7688	0.0244
	5-2/5-11	S_2 /S_{11}	0.3354	0.6559	0.0087
	5-3/5-12	S_3 /S_{12}	0.2298	0.7148	0.0554
P_{C1} , P_{C2} , P_{C3} , P_{C4}	5-4/5-13	S_4 /S_{13}		0.9968	0.0032
	5-5/5-14	S_5 /S_{14}		0.9973	0.0027
	5-6/5-15	S_6 /S_{15}		0.9959	0.0041
	5-7/5-16	S_7 /S_{16}		0.9987	0.0013
P_{A1}, P_{A2}	5-8/5-17	S_8 /S_{17}		0.9918	0.0082
	5-9/5-18	S_9 /S_{18}		0.9682	0.0318
I_{T1}, I_{T2}, I_{T3}, I_{T4}	5-24/5-37/5-50	S_{24} /S_{37} /S_{50}	0.2613	0.6654	0.0733
	5-25/5-38/5-51	S_{25} /S_{38} /S_{51}	0.2076	0.7175	0.0749
	5-26/5-39/5-52	S_{26} /S_{39} /S_{52}	0.2485	0.7407	0.0108
	5-27/5-40/5-53	S_{27} /S_{40} /S_{53}	0.3022	0.6154	0.0824
I_{C1}, I_{C2}, I_{C3}	5-28/5-41/5-54	S_{28} /S_{41} /S_{54}		0.9957	0.0043
	5-29/5-42/5-55	S_{29} /S_{42} /S_{55}		0.9962	0.0038
	5-30/5-43/5-56	S_{30} /S_{43} /S_{56}		0.9984	0.0016
I_{S1}, I_{S2}, I_{S3}	5-31/5-44/5-57	S_{31} /S_{44} /S_{57}		0.9453	0.0547
	5-32/5-45/5-58	S_{32} /S_{45} /S_{58}		0.9358	0.0642
	5-33/5-46/5-59	S_{33} /S_{46} /S_{59}		0.9536	0.0464
I_{A1}, I_{A2}, I_{A3}	5-34/5-47/5-60	S_{34} /S_{47} /S_{60}		0.9422	0.0578
	5-35/5-48/5-61	S_{35} /S_{48} /S_{61}		0.9447	0.0553
	5-36/5-49/5-62	S_{36} /S_{49} /S_{62}		0.9942	0.0058
E_{T1}, E_{T2}	5-70/5-71	S_{70}/ S_{71}	0.2579	0.7232	0.0189
			0.1984	0.7665	0.0351
E_{A1}, E_{A2}	5-72/5-73	S_{72} /S_{73}		0.9729	0.0271
				0.9903	0.0097
Material Preparation Subsystem P	1-21/1-22	$C_{21\text{-}22}$		0.9824	0.0176
Material Dispatch Subsystem I	3-66/3-67/3-68	$C_{66\text{-}68}$		0.9236	0.0764
Information Management Subsystem E	6-75	C_{75}		0.9917	0.0083

For the fault diagnosis of the emergency material dispatch system, assuming that the failure of the emergency material dispatch system occurs, the output signal is fault injected, i.e., the probability P(2)=1 when the failure of the output signal node generates a failure is injected into the Bayesian network as an evidence variable over and over again, and the posterior probability distribution of each sub-node can be obtained by reasoning and calculating again, i.e., the state probability distribution of the non-initial signal flow in the GO diagram of the emergency material dispatch system is shown in Table 3.

Table 3. Probability distribution of sub-nodes of Bayesian network[Owner-draw]

Serial number	Signal flow sub-nodes	Positive reasoning P(2)	Reverse Reasoning P(2)
1	$S_{19\text{-}20}$	0.2735	0.6458
2	$S_{21\text{-}22}$	0.1354	0.5447
3	S_{23}	0.1241	0.2483
4	$S_{63\text{-}65}$	0.3013	0.6201
5	$S_{66\text{-}68}$	0.1897	0.7246
6	S_{69}	0.0116	0.0214
7	S_{74}	0.0769	0.1739
8	S_{75}	0.4428	1.0000

From the forward inference failure data in Table 3, it is obtained that the system succeeds that the output signal S_{75}, the probability of normal operation is 0.5572, and the probability of system failure repair is 0.4428. Meanwhile, the reverse inference failure data in Table 3 demonstrates the posterior probability distribution of failure of each sub-node in the Bayesian network under the failure of the emergency material dispatch system and then finds the weak link of the system.

Comparing the a priori probability and posterior probability at different times of dispatching work (see Figure 4), it can be visually seen that in the case of failure of the emergency material dispatching system, the failure probability of $S_{66\text{-}68}$ is the highest and $S_{19\text{-}20}$ is the second, indicating that the material dispatching subsystem is the weak link of the emergency material dispatching system.

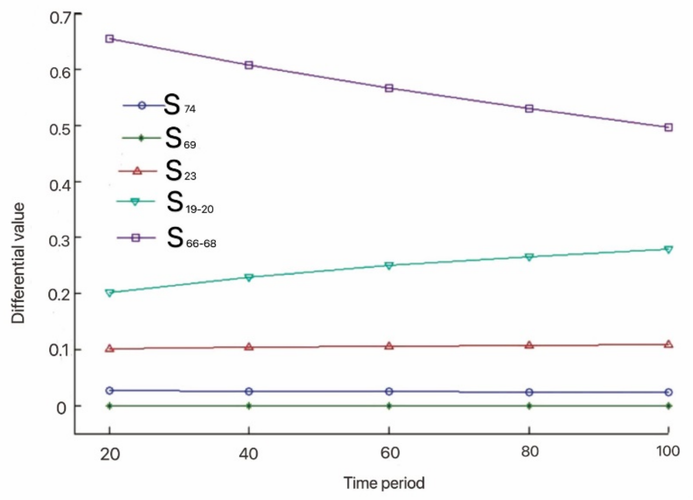

Fig. 4. Comparison of prior probability and posterior probability [Owner-draw]

5 Conclusion

In conclusion, in the case of failure of the emergency material dispatching system, the focus should be on eliminating the failure of the material dispatching subsystem, followed by eliminating the problems of the material preparation subsystem. The results show that material transportation time, emergency vehicle waiting time, implementation plan development time, satisfaction with the quantity of materials at the affected site and agility of the dispatching information system are the most critical influencing factors on the reliability of the emergency material dispatching system. Secondly, the time of material collection, the agility of the dispatching method, the satisfaction of the affected site on the emergency time and material quality, and the smooth communication time of feedback information also significantly affect the system's reliability. Therefore, in the material dispatching link, the material transportation time should be reasonably formulated, the traffic conditions of different road sections at different times should be summarized and analyzed, and the material transportation should be prioritized according to the time with high reliability. Consider weather conditions and traffic jam frequency, optimize transportation paths, reduce the waiting time of emergency vehicles, and buy more time for emergency material dispatching and rescue; improve logistics information release, improve the agility of emergency material dispatching information system, develop corresponding emergency solutions, reduce dispatching time and its fluctuation range, and improve the reliability of emergency material dispatching. Meanwhile, grasping the satisfaction and punctuality of feedback information from the affected points is also an effective way to improve the reliability of the whole emergency material dispatching system.

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