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Construction of risk response scenarios for the emergency material support system

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Abstracts

Representing disaster scenarios and evaluating the emergency material support system (EMSS) is crucial to enhance emergency material support capabilities. Current representation methods for EMSS mostly focused on the task response procedure during emergencies, rarely involved the response process analysis for disaster scenarios. This study utilizes an ontological method to construct a representation of risk response scenarios for the EMSS. It can be achieved by representing scenario feature elements, scenario structure elements, scenario constraint elements, and scenario attribute elements through the four dimensions. The scenario representation can generate different setting schemes for EMSS. An example scenario was presented based on the measures implemented by the Chinese government during the COVID-19 epidemic's closure of Wuhan. The findings of this research can provide valuable support for making risk-informed decisions regarding EMSS.

Keywords: Emergency material support system (EMSS); Scenario construction; Ontological method

1. Introduction

The emergency material support system (EMSS) plays a crucial role in enhancing disaster emergency preparedness capabilities [1]. A particularly effective way to respond to natural disasters is to undertake appropriate measures for disaster preparedness to minimize the adverse impact as much as possible. Federal Emergency Management Agency (FEMA) divides the disaster management cycle into four stages: disaster prevention, pre-disaster preparation, initial post-disaster response, and post-disaster recovery [1]. The construction of EMSS is a vital component of disaster prevention, and forms the foundation of the emergency rescue effectiveness across the other three stages. During a significant emergency, the availability of emergency materials can directly affect the event's

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development situation [1]. Public health crises, such as the outbreak of infectious diseases, frequently result in a rapid and explosive increase in the demand for emergency materials. These materials may face issues such as uncertain demand and delayed supply. For instance, during the initial outbreak of the novel coronavirus pneumonia in Wuhan, the demand for emergency materials surged significantly.

Scenario is a depiction of a future state of the affairs that outlines a series of factual events leading from its present state towards the anticipated future state [2]. Scenario construction is one of the most commonly used methods for studying the future development of sudden disaster events [3]. The process involved in EMSS are fundraising, transportation, and distribution. Given the massive quantity, diversity, and sustained duration of emergency materials needed during disasters, the capability to acquire a considerable amount of such materials in disaster scenarios has emerged as a critical aspect of disaster response.

Existing research on the construction of EMSS has predominantly focused on issues such as the construction of material allocation mechanisms during emergencies [4], and the role of non-governmental organizations in emergency material allocation [5]. These existing studies have often prioritized the "task response" process [6] while providing less analysis on the "scenario response" process [7]. Additionally, the current EMSS evaluation models only assess risk levels and key links, and does not include the disaster-inducing factors and disaster-bearing bodies in the whole process of the occurrence and evolution of emergencies. Therefore, it becomes challenging to discern precursor deficiencies in complex scenarios as the models fail to consider the intricate mechanisms of occurrence and evolution, as well as the severity of direct and secondary derivative events. As a result, deterministic EMSS assessment plans are inadequate for addressing uncertain problems. This study utilizes the <I-N-C-A> method in ontology to construct scenarios based on the analysis of the characteristics of disaster scenarios. Subsequently, scenario representation is applied to the EMSS, proposing three types of EMSS evaluation: classification oriented, sorting oriented, and self-examination oriented [8]. Describing the emergency material support process from the scenario-task matching perspective is essential in minimizing the risk of EMSS in disaster situations and enhancing its capability. The significance of this study lies in developing a risk response scenario that considers the evolutionary process of emergencies, which can be integrated into EMSS assessment. The main findings of this study provide an effective decision support regarding risk management in EMSS.

The remainder of this study is organized as follows. Section 2 presents the scenario construction scheme, outlining the representation of scenario elements and material support system settings. Section 3 provides an illustration of the task description of the EMSS under COVID-19 as an example of scenario construction. Finally, Section 4 summarizes the conclusions of this study.

2. Scenario construction design

2.1. Scenario element representation

Disaster case scenarios are typically represented using three principal representation methods: ontology representation [9], architectural representation [10], and tree structure representation [11]. Among these, ontology representation is the most expressive, having the capability to effectively manage complex scenario events, and it is not limited by semantics. Hence, this study employs ontology representation and uses "*Issue-Node-Constraint-Annotation*" in ontology to depict disaster scenarios. The four elements refer to issues, nodes, constraints, and annotations and correspond to scene feature elements, scene structure elements, scene constraint elements, and scene attribute elements.

(1) *Issue*: Refers to the situational feature elements in the disaster chain, mainly summarizing the overall input case, indicating the type of disaster scenario, basic information, application field, etc., matching with the determined goals in the research scenario, and quickly locating the corresponding scenario set. This is the first step in scenario matching, formalized expression: *Issues<id: I0001, name: XXX, type_dis: "COVID-19", time: "2020.1.6", address: "city", application: "decision"> ((attribute items [attribute-qualifiers]), value).* Among them, *id* is the number corresponding to the issue; *name* is the name of the risk scenario; *type_dis* is the type of disaster; *time* is the time when the disaster scenario occurred; *address* is the geographical location where the disaster scenario occurred; *application* refers to the scope of application that this case can apply to, and in this case, it refers to emergency material support.

(2) *Node*: To represent the situational structural elements in the disaster chain, entity objects that play a central role in the scenario evolution process must be identified. These objects, based on the disaster system theory, encompass disaster-inducing factors and disaster-bearing bodies. By combining different types of nodes, individuals can develop an understanding of the disaster scenario's general outline, gain insights into the root causes of events, external factors, and current outcomes, formalized expression: *node< id: N0001, name: XXX, type: (“Induced disaster factors”, “Hazard bearing body”) > ((attribute items [attribute-qualifiers]), value).* Among them, *id* is the number corresponding to the node; *name* is the name of the node; *type* indicates the role of the node in the scenario.

(3) *Constrain*: The normative constraints faced by nodes in the evolution path selection process of disaster chain scenarios, including rule constraints, response constraints, and time constraints, among which time constraints are included in the rule constraints and response constraints, formalized expression: *Constrains <id:C0001, name: XXX, rule constraints [type, elements, time], respond constraints [people number, material resources, transportation, time]>.* Among them, *id* indicates the constraint number; *name* is the constraint name; Rule constraints are rule constraints, *type* is the type of rule constraint, *elements* are the scenario element pairs to which the rule constraint applies, and *time* is the time range to which the rule constraint applies; *Response constraints* refer to emergency measures taken during the occurrence of a scenario, with *people number* indicating the manpower invested in the response process, *material resources* indicating the material resources invested in the response process, *transportation* indicating the transportation invested in the response process, and *time* indicating the time range within which the response constraint applies.

(4) *Annotation*: Representing the scenario attribute elements of each node in the disaster chain scenario involves depicting the collection of different performance carriers presented by nodes under constraints. Set h ($h_1, h_2, \ldots, h_n$) as the attribute list of disaster causing factors, taking the epidemic as an example, including factors such as susceptible populations, infected populations, and latent populations; a ($a_1, a_2, \ldots, a_n$) is the attribute list of disaster bearing factors, taking material support infrastructure as an example, including physical elements, information elements, management elements, etc. Each attribute is described using a binary ($value_i$, t_i), which represents the specific value of the attribute and its valid timestamp.

2.2. Scenario Setting for Material Support System

Through an analysis of the component elements comprising risk representation scenarios, it is evident that varying manifestations of each element will result in distinct scenarios. Different evaluation-oriented scenarios can be derived based on the diverse evaluation purposes of the material security system, including classification-oriented scenarios, sorting-oriented scenarios, and self-examination oriented scenarios.

Depending on the number of evaluation objects, two distinct evaluation object scenarios can be derived: single-object and multi-object scenarios. The representation of scenario elements reflects the number of multiple evaluation objects as various scenario cases, which arise from different *Nodes* under the same *Issue*, *Constrain*, and *Annotation*.

Depending on the number of evaluation stages, three different evaluation stage scenarios can be derived: single stage, multi-stage, and full stages. The representation of scenario elements illustrates the number of multiple evaluation stages as diverse scenario cases resulting from different *type Constrains* within the same *Issue*, *Annotation*, and *Node*.

Depending on the number of evaluation times, two types of static and dynamic evaluation scenarios can be derived: single time and multi-time scenarios. The representation of scenario elements showcases the number of points in multiple evaluations as diverse scenario cases that emerge from different types of *time Constrains* within the same *Issue*, *Annotation*, and *Node*.

Three distinct evaluation information scenarios can be derived based on the complexity of the evaluation information: single information scenario (which involves a single source and a single form of information), multi-source isomorphic information scenario (which involves multiple sources but the same form of information), and multi-source heterogeneous information scenario (which involves multiple sources and multiple coexisting forms of information). The differences in the complexity of the evaluation information in the scenario representation are often manifested in the disparity of constraint rules.

3. Case study

As an example of establishing a EMSS scenario, the measures taken by the Chinese government to control the transmission of the original strain of COVID-19 in Wuhan during the city's closure serve as a fitting case study. To contain the spread of the epidemic, the Chinese government regulated entry and exit from Wuhan between January 23rd, 2020 and April 8th, 2020. To identify the factors that caused the disaster and the entities that bore the impact during the lockdown period, we analyzed text data from press conferences held by the China State Council Joint Prevention and Control Mechanism during the closure period. A knowledge graph was utilized to identify disaster-inducing factors and disaster-bearing bodies by constructing a graph composed of interconnected nodes and edges. We identified nodes by segmenting sentences from press conferences and labeling segmented words as nodes. We also established links between nodes using neural network-dependent syntax analysis algorithms to extract causal relationships between nodes [12]. The analysis results are depicted in Figure 1, which reveals that the primary transmission nodes of disaster-causing factors from the city's closure to the entity bearing the impact included rice, frozen meat, vegetables, and aquatic products.

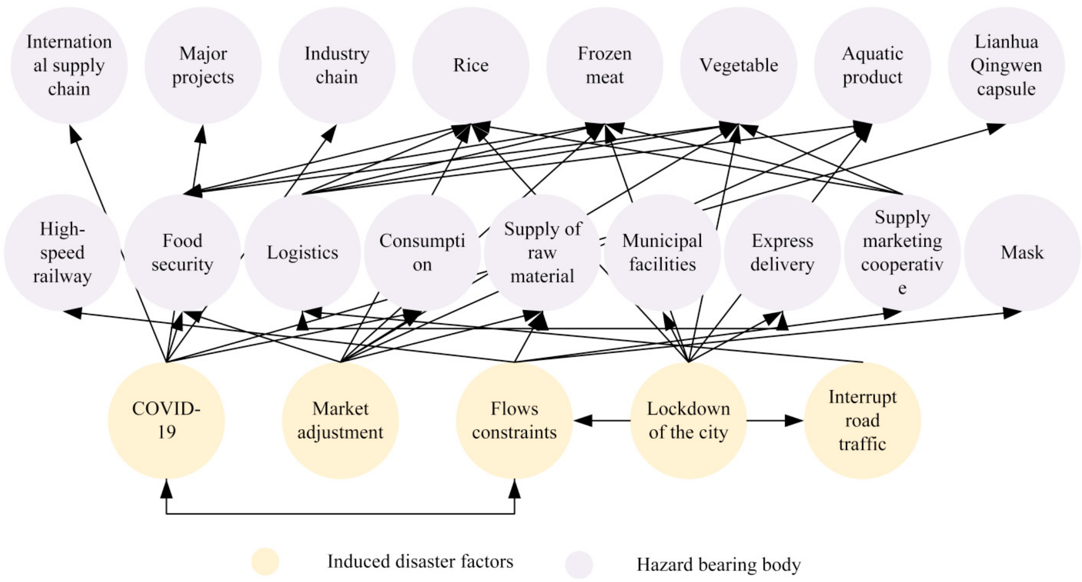

Fig. 1. Node relationship mining

Hence, the material support task during the COVID-19 pandemic, with a single assessment object, closure link, and closure time point can be represented as follows:

Issues <id: I0001, name: example scenario, type_dis: "COVID-19", time: "January 23rd, 2020", address: "Wuhan", application: "emergency material support" >

Node <id: I0001, name: example scenario, type: ("Induced disaster factors", "Hazard bearing body") > (attribute items [Lock down of the city - Rice/ Frozen meat/ Vegetables/ Municipal facilities/ Express delivery]>

Constrains <id: I0001, name: example scenario, rule constraints [COVID-19, Lock down of the city- rice, January 23rd, 2020 -April 8th, 2020], respond constraints [13.7 million people, Rice/ Frozen meat/ Vegetables/ Masks/ Aquatic products, Express delivery/High-speed railway]>

h (susceptible population, infected population, latent population, January 23rd, 2020)

a (Physical element, Information element, …, Management element, January 23rd, 2020)

This scenario representation method can also be used to represent material support scenarios under the conditions of *Market adjustment*, *Flows constraints* and other disaster causing factors.

4. Conclusions

The construction of EMSS is a critical component of disaster management. Using the ontological method, this study constructed a risk response scenario representation for the EMSS by incorporating scenario feature elements, scenario structure elements, scenario constraint elements, and scenario attribute elements into the four dimensions of <I-N-C-A>. By examining the measures taken by the Chinese government during the closure of Wuhan amid the COVID-19 epidemic, we presented an exemplary scenario. Compared to traditional methods, this paper provides a more detailed delimitation of the scenario deduction process and conducts a comprehensive analysis of the constituent elements. This allows us to depict the intricate mechanisms of the occurrence and evolution of disaster-causing factors, as well as disaster-bearing entities in unforeseen events. By providing support for risk decision-making in the EMSS, the scenario highlights the need for further research into the transformation and mapping rules for disaster chain scenarios. By doing so, we can create a complete disaster scenario situation deduction system, which can depict the severity of direct and subsequent secondary derivative events, and further bolster risk management. Due to the difficulty in collecting the basic data on emergencies, including information on time, location, and risk factors, as well as relevant data on disaster-related entities, we relied on text mining technology for data extraction in the case study. In the future, the scenario assessment can be improved by using more effective modeling methods, such as fault tree analysis, to comprehensively analyze the impact of different scenario events. This would help to minimize subjectivity and ambiguity associated with scenario event analysis.

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