Study on Spatiotemporal Knowledge Graph of Emergency Scenarios

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ABSTRACT

The emergency scenario is a frontier scientific issue in emergency research; it contains various information types and has complex internal logic. In order to solve the problem of lacking a structured expression method for analyzing scenarios, this paper utilizes a spatiotemporal knowledge graph to express complex knowledge while embedding temporal and spatial information into emergency scenarios, transforming traditional static information into entities, attributes, and relationships with dynamic characteristics, and realizing qualitative and quantitative analysis of scenarios from document to data level by constructing pattern layer and data layer. Furthermore, this paper introduces a case study, demonstrating that emergency scenario analysis based on a spatiotemporal knowledge graph provides a scalable path to analyze and define scenarios while enabling qualitative and quantitative presentation of the entire development process.

CCS CONCEPTS

• **Information systems** → **Information integration**; • **Applied computing** → **Multi-criterion optimization and decision-making**.

KEYWORDS

Emergency, Scenario, Dynamic, Spatiotemporal knowledge graph

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1 INTRODUCTION

As the complexity of emergencies continues to increase, the data involved has the characteristics of "massive data and difficult to find knowledge," which poses a challenge for decision-makers to obtain data and comprehend scenarios quickly. In order to analyze a scenario more accurately, we first need to define its components and, secondly, put forward a data model to express its dynamic features, as scenario evolution is highly related to time and space. Scenario analysis and knowledge graphs provide methods to tackle the two issues.

The concept of "scenario" was first proposed in the book "The Year 2000" in 1967 and defined as - "Scenarios are hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points. "[7]. Since the 1990s, there have been many discussions on a scenario in emergencies. In general, the common characteristics of elaborating scenarios reflect in two aspects[9]: first, a scenario contains multiple elements that influence each other; second, it dynamically changes over time and space. The current definition of scenarios focuses on qualitative descriptions, and few studies clearly define emergency scenarios' components, internal relationships, and spatiotemporal characteristics. This paper defines scenarios based on the emergency EOC model[5][6], a conceptual model of emergencies proposed before.

Analysis and construction of scenarios require multiple aspects of data[3], such as time, locations, environmental information, and data related to disaster bearers. Building structured scenarios needs to follow specific processes to analyze data attributes, extract knowledge and relationships, and simultaneously integrate these structured data at the semantic level. Semantic fusion is a complex problem, but we can only comprehend how a scenario evolves and make predictions about scenario development by integrating data of different scales, precisions, structures, sources, and correlations. It must find a model that can express data, knowledge, and relationships and support dynamic and static quantitative scenario analysis. The knowledge graph method is an essential means to achieve data modeling.

Most current knowledge graphs are on static knowledge; however, the evolution of scenarios is highly related to time and space, so expressing time and space is vital in constructing scenarios.

First, the scenario evolution reflects a kind of dynamics brought about by changing time and space. Secondly, part of knowledge is only valid at a specific time and space. For example, the shape of a building changes significantly before and after a strong earthquake. This paper chooses the spatiotemporal knowledge graph to analyze and express data for the following reasons: (1) it supports structured knowledge and multiple semantics[4]. (2) it can effectively express multi-dimensional and multi-level concepts, entities, and relationships, which help achieve data classification for complex scenarios[12]. (3) it provides a network data structure, and considering that the scenario development also presents a network form, it is feasible to construct a scenario using spatiotemporal knowledge graph technology[1]. (4)the spatiotemporal knowledge graph is divided into pattern and data layers. The pattern layer provides general concepts and knowledge. The data layer extends the pattern layer, providing data value reflecting the scenario status. The data layer is the foundation of quantifying scenarios[8]. (5) it can distinguish similar semantic relationships in time and space, thereby capturing the sequential information. For example, the static knowledge graph cannot identify "starts with" and "ends with" nor the spatial relationship between "outside" and "inside," but the spatiotemporal knowledge graph can. (6)it can improve the accuracy of prediction results with spatiotemporal information[10]. (7) it is close to human thinking, and the scenarios constructed on the spatiotemporal knowledge graph are easy to understand by both computers and humans. In the future, precise applications can be developed on the spatiotemporal knowledge graph, for example, scenario-specific semantic search and intelligent scenario prediction[11].

In general, (1) this paper clearly defines the connotation of emergency scenarios, that is, its components, internal relationships, time and space characteristics; (2) construct a spatiotemporal knowledge graph of emergency scenarios to achieve structuring and quantification of emergency data[13][2]. The chapters are as follows: Section 1 is a literature review; Section 2 defines emergency scenarios based on the emergency EOC model[5][6] ; Section 3 explains the temporal and spatial characteristics of scenarios and proposes a process for constructing a scenario oriented spatiotemporal knowledge graph; Section 4 introduces a case to verify the effectiveness of the method; Section 5 provides summary and outlook.

2 MULTI-DIMENSIONAL SCENARIOS FOR EMERGENCIES

From the perspective of "what you see is what you get." the emergency scenarios are the sum of everything that happens at the disaster site. The multi-dimensions of a scenario correspond to multiple aspects of an emergency. From the perspective of emergency management, we usually pay close attention to the inducement of emergencies—elements, the affected entities—objects, the specific background—environmental conditions, the negative impact—consequences, the measures taken on the scene—emergency management and response, and the spatiotemporal information. A single scenario contains all the above aspects.

This paper defines a scenario as a group of spatiotemporal related elements (*E* for short), object (*O* for short), consequence (*C* for short), environmental condition (*U* for short), response and management (R&M, *R* for short). Scenario analysis has two relatively independent routes, as shown in Figure 1: the first is to analyze an emergent event using the EOC model (the middle of Figure 1); the second is to analyze emergency management and response (the left side of Figure 1); the latter is on the former, and the two intertwined development constitutes an emergency. Emergency scenario analysis is grounded in previous research results — the EOC model[5][6] (the middle of Figure 1), which provides a framework for quantifying emergencies and scenarios, where *S* represents the set of scenarios.

The multi-dimensional scenario analysis method (as shown in Figure 1) is a quantitative analysis method that helps clarify essential components, attributes, relationships, and data characteristics involved in scenarios. More than that, complex scenario analysis can be achieved based on the same framework.

3 BUILDING SPATIOTEMPORAL KNOWLEDGE GRAPH FOR SCENARIOS

We split information according to the hierarchical structure of "emergency–scenario–elements, objects, consequences, emergency management and response, Time and Locations". Building a spatiotemporal knowledge graph with scenario evolution visually shows what critical transitions have occurred in the emergency, thus promoting the decisionmaker's understanding of the emergency occurrence and development process. Scenarios connect with a large amount of knowledge and relationships, and based on these data, making inference rules helps infer hidden facts. The spatiotemporal knowledge graph is scenario-oriented, which builds around scenario evolution rather than a single factor. If a knowledge graph sets e_i, o_i, c_i, u_i, r_i, ζ_i as the center, it will lose the center node, increasing the difficulty of understanding emergencies, moreover, if the influence of time t is superimposed, the knowledge graph will be more complex and less clear.

Figure 2 provides a scenario-centered data representation framework, which includes modeling the EOC components, time, and space information. This integrated information contains dynamic characteristics; analyzing them is the basis for studying scenario evolution. It can be intuitively seen from Figure 2 that data and relationships contained in scenarios are very complex. When analyzing the text of emergencies, we can divide scenarios according to time order and then get a set of scenarios with time stamps. By browsing the scenario set, we can quickly grasp the context of emergency evolution.

The critical aspects of building a spatiotemporal knowledge graph are as follows:

(1) Node type: emergency, scenario, element, object, consequence, environmental condition, emergency response and management;

(2) Relationship type: The first is the relationships defined by the EOC model, such as "Acton, Induce, Contain, Belongto"; they are proposed to describe mutual influences among scenario components. The second is the time relationship, and the third is the space relationship.

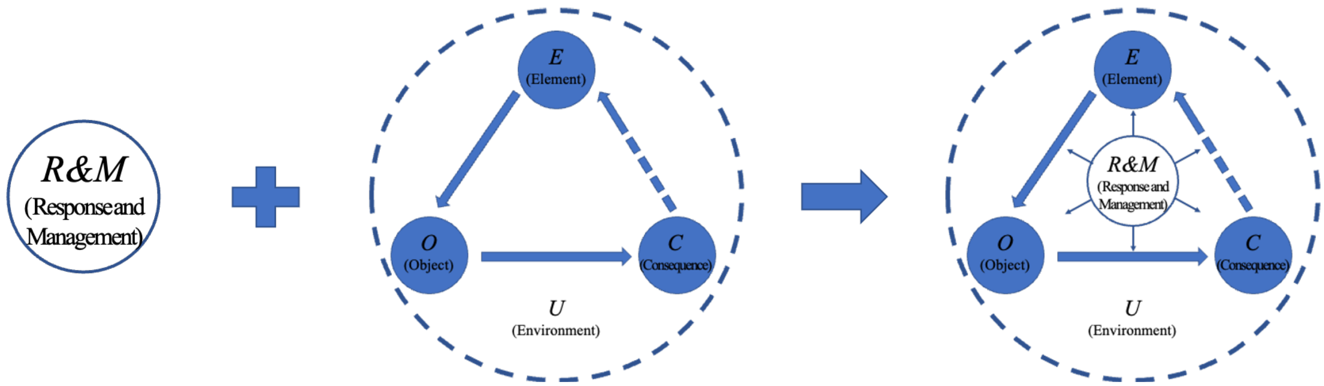

Figure 1: Scenario Analysis Based on the EOC Model

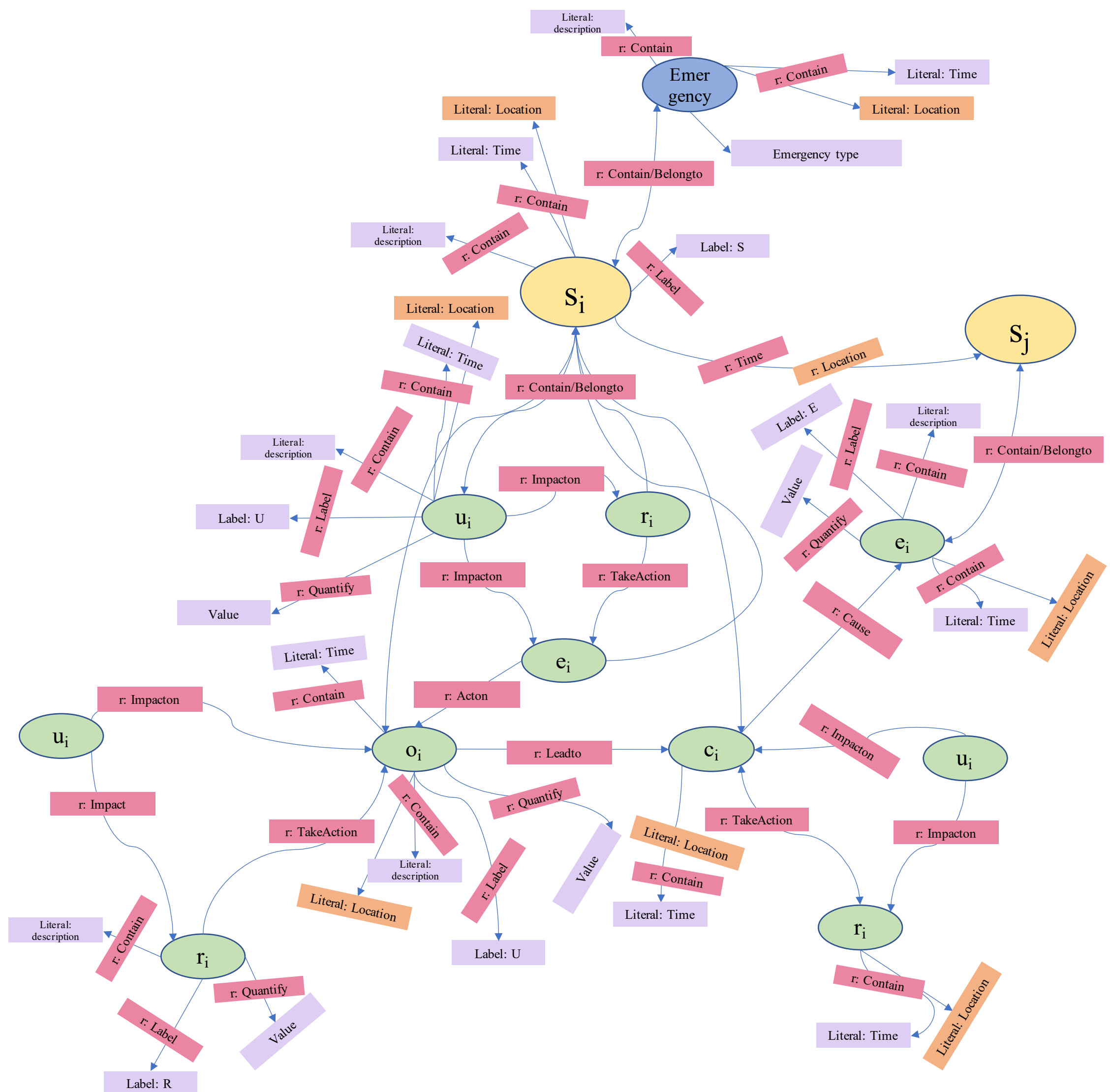

Figure 2: Graph Data Representation Framework Based on the EOC Model

(3) Qualitative description: using "Literal: description; Label: S, E, O, C, U, $R\&M$" (see Figure 2) to qualitatively describe basic information, attributes, and value range of S—(E, O, C, U, R and relationships).

(4) Quantitative description: defining "attributes and value" (see Figure 2) to quantitatively describe the attributes and value range of S-(E, O, C, U, R and relationship).

(5) Time description: associating time with S-(E, O, C, U, R and relationship) to realize a dynamic study of changing scenarios and their components.

(6) Space description: using GeoJSON format and azimuth description to express spatial attributes.

It is complex to describe the numerous relationships and attributes of scenarios. There is a phenomenon of information dimension increase in scenario analysis, making it impossible to clarify all kinds of relationships simultaneously. In contrast, the stability of the pattern layer of the knowledge graph makes it possible to integrate mass knowledge and gradually enrich attribute dimensions of scenarios. Figure 3 shows the pattern layer of the spatiotemporal knowledge graph for multi-dimensional scenarios based on the EOC model.

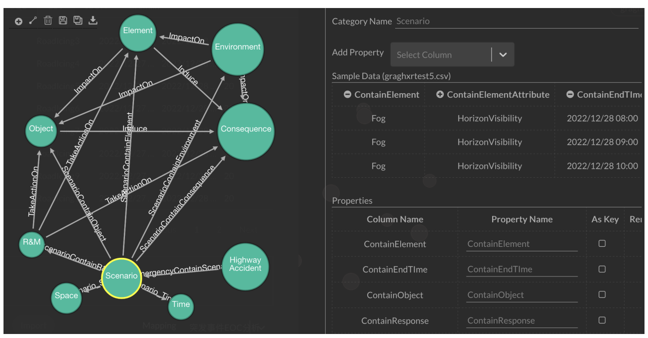

Figure 3: The Pattern Layer of Scenarios Related Knowledge Based on the EOC Model

Figure 3 integrates all the relationships defined by the EOC model, such as the relationships defined by the scenario containing elements (ContainElement), objects (ContainObject), and the "ImpactOn" of elements on objects. This paper constructs the spatiotemporal knowledge graph by constructing the model layer (ontology) and the data layer (neo4j graph database[1]).

4 CASE STUDY

A Real case: At around 7:46 a.m. on December 28, 2022, Zhengzhou Zhengxin Yellow River Bridge suddenly experienced dense fog, and multiple car crashes occurred in north-south and south-north directions near the middle line. At the time of the accident, there was icing on the bridge surface, and the visibility was more than ten to fifty meters. According to the weather forecast released by Zhengzhou Meteorological Service Center on December 27, the minimum temperature from the night of December 27 to December 28 was minus 4 to minus 3 degrees Celsius. According to the framework given in Figure 2, Table 1 briefly summarizes the basic situation of the accident and delimits two typical scenarios: "S_1: road icing" and "S_2: multi-vehicle collision".

Based on the scenario ontology in Figure 2, a spatiotemporal knowledge graph is generated to realize the scenario evolution analysis with time and location tags. The spatiotemporal knowledge graph provides an object-oriented, flexible, and dynamic network structure that adapts to the value of multiple dimensions of scenarios. Some previous studies have used relational data to analyze the data and relationships contained in emergencies. However, the method based on relational data makes it difficult to describe the attribute information contained in the relationship itself. This paper uses the graph data to study scenarios to make up for this shortage. Figure 4 shows the case of freezing accidents on expressways, including the expression of E, O, C, U, $Time$, $Location$, and internal relationships.

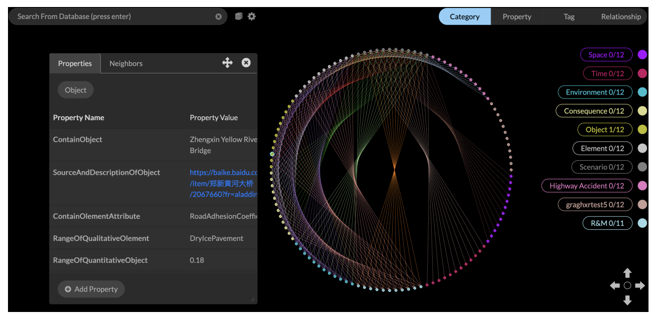

Figure 4: Scenario Diagram Data Representation of the Case

The case is not complicated, so we divide the case into two scenarios. Therefore, there is little data for complex scenario analysis and deduction on this data basis. The scenario ontology defined based on the EOC model agrees on the occurrence mechanism of freezing disasters and the value range of each scenario component. In order to solve the problem of needing more accident data, this paper randomly generates ten simulation data about road icing and multi-vehicle collisions based on the constraints of rules to analyze better and deduce the scenario. As shown in Figure 5, the geographical location of the scenario is expressed. In the realistic background of difficult access to disaster case data and lack of accident information, the characteristics of generating simulation data based on the emergency scenario ontology defined based on the EOC model are significant.

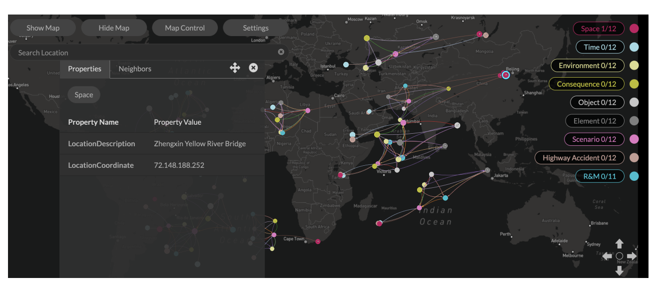

Figure 5: Geospatial Information Expression of Scenario

[1]https://neo4j.com

Table 1: Review Accident on Zhengxin Yellow River Bridge

Datatype	No.1		No.2	
Scenario	S_1	Road Icing	S_2	Multi-vehicle Collision
Time	t_1–$t_{1,1}$, t_1–$t_{1,2}$	2022-12-27, 2022-12-28	t_2	2022-12-28T07:46:00
Element	e_1	Fog	e_2	Ice
Object	O_1	Zhengxin Yellow River Bridge	O_2	Vehicles
Consequence	C_1	the Bridge Surface Icing	C_2	Vehicle Skid, Vehicles Collision
Environment	U_1	Lowest temperature of -4 -3℃	U_2	dense fog
Response & Management	R_1	Zhengzhou issued weather forecast on 2022-12-27	/	/

The spatiotemporal knowledge graph constructed based on the EOC model is flexible, and what is more, it forms an essential judgment of the overall situation and details of scenarios. It can flexibly implement the essential functions of information addition, deletion, storage, and retrieval and also realize scenario calculation and inference functions based on the scenario law, as shown in Figure 6. In this paper, the scenario calculation rules are predefined at the scenario ontology level to calculate the scenario severity value. The green dots in the figure represent the severity of the consequence, as the Severity Value of Consequence is defined on the Y-axis. Each green dot is associated with a scenario, and the blue dots represent the scenario. The larger the circle, the more serious the scenario. The X-axis represents the time development sequence, and each component included in the scenario on the X-axis is arranged along the time development sequence; the value of these components can be obtained by clicking on these dots. The spatiotemporal knowledge graph constructed in this paper supports the scenario's definition, display, analysis, query, and associated spatial and temporal information. Furthermore, scenario analysis and calculation can be realized by adding rules and formulas, which is significant for understanding scenario evolution and making decisions based on scenario perception.

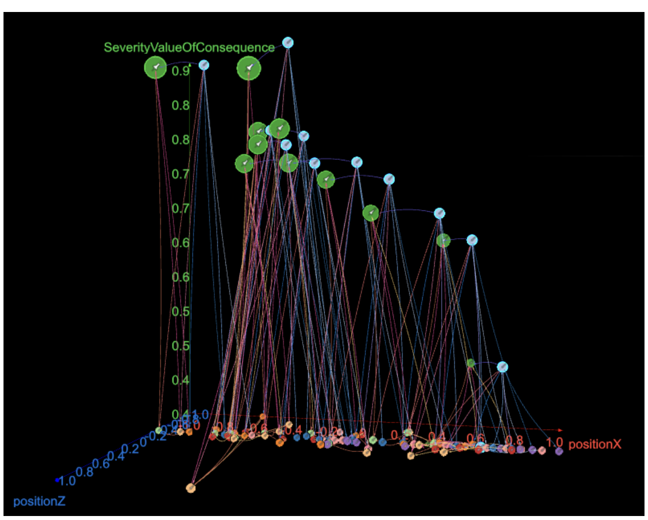

Figure 6: Display Scenarios in Chronological Order and Severity Value

5 CONCLUSION AND RESEARCH PROSPECT

This paper proposes to analyze and construct emergency multi-dimensional scenarios using the EOC model and spatiotemporal knowledge graph method. This structured scenario analysis method clearly describes the EOC components, spatiotemporal information, and relationships contained in scenarios, and it splits information from text to small granularity. Scenario analysis contains two levels: pattern level and data level. Based on the connotation of the scenario, we construct scenario ontology integrated with the EOC model at the pattern level. The pattern layer is instantiated at the data level by inputting actual disaster or simulated data values. Further, we generate different scenario combinations by adjusting parameter values to predict scenario evolution.

Based on multi-dimensional scenario analysis, knowledge graph technology is integrated to add the expression of time and space information, which makes knowledge graphs express both the static and dynamic characteristics of scenario evolution. A scenario knowledge graph with spatiotemporal properties can display data more intuitively and also help improve the quality of scenario retrieval and reasoning.

Building high-quality spatiotemporal knowledge graphs for emergencies is a challenging problem. The combination of spatiotemporal knowledge graphs and scenario research is a new research trend, which not only includes the use of semi-automatic or automatic methods to build dynamic knowledge, such as dynamic entities and dynamic relationships to assist in scenario temporal reasoning but also includes the construction of more flexible and more extensible scenario models matching spatiotemporal knowledge graphs. In the future, we will pay more attention to analyzing and constructing dynamic scenarios for catastrophes and improve the ability of scenario deduction.

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