Ontology-based Knowledge Modeling for Emergency Response to Shipboard Hazardous Cargo Accidents

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Abstract. The ontology-based knowledge modeling is introduced into the knowledge management and service of shipboard hazardous cargo accident on the water, the ontology model layer and data layer of shipboard hazardous cargo accident emergency relief are established, the structured multi-source knowledge of the non-structured expression of shipboard hazardous cargo accident emergency is realized, the ontology mapping algorithm of shipboard hazardous cargo accident emergency is designed, and the multi-source heterogeneous knowledge fusion of shipboard hazardous cargo accident emergency is realized to further integrate and transform the existing accident information advantages into decision-making advantages, effectively enhance the emergency response capability and improve the emergency management work.

Keywords: water emergency; shipboard hazardous cargo; ontology modeling; mapping relationships

1 Introduction

Ontology originated from a philosophical concept and was first introduced to the field of artificial intelligence by Neches and other scholars in the 1990s to solve the knowledge-sharing problem. Neches [1] defines ontology as "the basic terms and relationships between terms that make up the vocabulary (set) of a subject area"; Gruber [2] proposes that "ontology is an explicit specification of a conceptual model"; Studer [3] proposes that "an ontology is an explicit formal specification of a shared conceptual model".

Maji [4] used an ontology to represent fire emergency, which can provide support for experts to deal with emergencies but is not very structured; Li Jun et al [5] constructed an ontology model of emergency cases oriented to case reasoning with the help of ABC ontology framework; Wang Fang [6] constructed FE-SUMO fire emergency ontology from fire accident, combustion elements, fire results, emergency organization, emergency resources, and emergency roles; Liu Yaqiong [7] studied its emergency scenario ontology for rain and snow traffic; Cai Mei [8] established dynamic scenario event chains with the help of ontology and gave a matching calculation method for event chains.

Emergency response plans are mostly in textual form, and related scholars have constructed emergency response plan ontologies to realize emergency response plan generation to assist decision-making. penadés et al [9] proposed that structuring emergency management knowledge can improve the efficiency of emergency response plan preparation and generation;

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Haghighi et al [10] constructed a medical emergency response ontology for stampede events, which can enhance the Liu [11] constructed a corresponding emergency plan ontology for geological disasters, and also combined Jena and Pellet inference engines to generate emergency decision plans; Ding Zhifei [12] through the study of several chemical plant emergency plans, concluded that the emergency plans are divided into personnel organization system, hazard source analysis, disaster prevention, and emergency actions in terms of content, and the knowledge and technology are divided into three types of entities: emergency rules, emergency actions, and emerging entities.

The ontology can both normalize and represent the knowledge of shipboard hazardous cargo accident emergencies on the water, retrieve and utilize the knowledge of shipboard hazardous cargo accident emergencies, and perform knowledge reasoning based on the emergency knowledge and related relationships. Due to the high requirement of knowledge accuracy for shipboard hazardous cargo accident emergencies and a large amount of knowledge involved, this paper adopts a semi-automatic construction method for ontology construction with the help of Protégé, an ontology construction tool.

2. Emergency relief ontology model layer construction

The shipboard hazardous cargo accident emergency ontology pattern layer is constructed based on the shipboard hazardous cargo accident emergency knowledge system, further unfolding all kinds of knowledge and obtaining a huge shipboard hazardous cargo accident emergency knowledge semantic network graph HCERKG (Hazardous-chemicals-accident Emergency-rescue Knowledge Graph), which can be expressed as follows. where C_{HCER}, R, and E represent the concept layer, concept entity relationship, and entity layer.

$$HCERKG = < C_{HCER}, R, E > \quad (1)$$

A further expansion of the knowledge of the conceptual layer C_{HCER} is expressed as follows. Where N_c, P_c, and R_c denote: node, edge, and relation, respectively. Node N_c is the relevant concept involved in C_{HCER}, R_c is the relationship between concepts, and P_c is the characteristic property inherent to the concept.

$$C_{HCER} =< N_c, P_c, R_c > \quad (2)$$

$$N_c = \{N_{c1}, N_{c2}, ..., N_{cn}\}, n > 1 \quad (3)$$

$$P_c = \{P_{c1}, P_{c2}, ..., P_{cm}\}, m > 1 \quad (4)$$

$$R_c = \{R_{c1}, R_{c2}, ..., R_{cq}\}, q > 1 \quad (5)$$

A further expansion of the knowledge of the entity layer E is expressed as follows. Where N_e, P_e, and R_e denote: node, attribute, and relationship, respectively.

$$E =< N_e, P_e, R_e > \quad (6)$$

$$N_e = \{N_{e1}, N_{e2}, ..., N_{en}\}, n > 1 \quad (7)$$

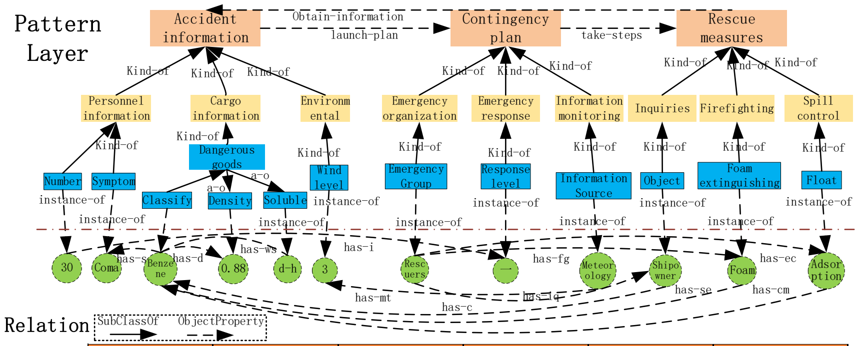
$$P_e = \{P_{e1}, P_{e2}, ..., P_{em}\}, m > 1 \quad (8)$$

$$R_e = \{R_{e1}, R_{e2}, ..., R_{em}\}, m > 1 \quad (9)$$

The conceptual entity relationship R describes the relationship between the conceptual layer C_{HCER} and the entity layer E, represented by the attribute rdf: type.

$$R = \left\{ \left(E_i, rdf:type, C_{HCERi} \right) \middle| \; E_i \in E, C_{HCERi} \in C_{HCER} \right\} \tag{10}$$

Through the formal representation of the concept layer C_{HCER} , entity layer R, and concept-entity relationship R of the shipboard hazardous cargo accident emergency knowledge network graph HCERKG, it is found that both concept edges and concept nodes or instance edges and instance nodes can be represented as a triadic structure. As shown in the Schematic diagram of the emergency response to shipboard hazardous cargo accidents ontology in Figure 1.



Data Layer

Abbreviation	Interpretation	Abbreviation	Interpretation	Abbreviation	Interpretation
coma	symptom	0.88	0.88g/ml	d-h	insoluble
Relationship	Interpretation	Relationship	Interpretation	Relationship	Interpretation
has-i	casualties	kind-of	belong	instance-of	instance
Relationship	Interpretation	Relationship	Interpretation	Relationship	Interpretation
has-d	density	has-mt	monitoring	has-cm	control method
Relationship	Interpretation	Relationship	Interpretation	Relationship	Interpretation
has-s	symptoms	has-se	extinguishant	has-iq	inquiries

Figure 1 Schematic diagram of the emergency response to shipboard hazardous cargo accidents ontology

2.1 Emergency relief core concepts

The core concepts in the field of shipboard hazardous cargo accident emergency response center on three points: hazardous cargo accident, emergency plan, and rescue measures, both the shipboard hazardous cargo accident emergency response ontology includes three local ontologies: accident ontology, plan ontology, and rescue ontology. The ontology pattern layer consists of a collection of core concepts, and the set of shipboard hazardous cargo accident emergency concepts (C_{HCER}) is expressed as follows.

$$C_{HCER} = \left\{ \begin{array}{l} C_{HCA} = \left\{ C_{Cargo\text{-}inf}, C_{Ship\text{-}inf}, C_{Envir\text{-}inf}, C_{Person\text{-}inf} \right\} \\ C_{EP} = \left\{ C_{EmR}, C_{EmR}, C_{EmO} \right\} \\ C_{RM} = \left\{ C_{iq}, C_{ig\text{-}i}, C_{p\text{-}p}, C_{f\text{-}c}, C_{b\text{-}s}, C_{f\text{-}a}, C_{l\text{-}sc}, C_{l\text{-}c} \right\} \end{array} \right\} \tag{11}$$

C_{HCA} represents the concept of information on hazardous chemical incidents, whereas $C_{Cargo\text{-}inf}$, $C_{Ship\text{-}inf}$, $C_{Envir\text{-}inf}$, and $C_{Person\text{-}inf}$ represent the concept of cargo information, the concept of vessel information, the concept of environmental information, and the concept of personnel information respectively; C_{EP} represents the concept of emergency response, where C_{EmR}, C_{InfD}, C_{EmO} represent the concept of emergency response, the concept of information monitoring and the concept of emergency organization respectively; C_{RM} represents the concept of implementation of rescue measures, where C_{iq}, $C_{ig\text{-}i}$, $C_{p\text{-}p}$, $C_{f\text{-}c}$, $C_{b\text{-}s}$, $C_{f\text{-}a}$, $C_{I\text{-}sc}$, $C_{I\text{-}c}$ represent the concept of inquiry, the concept of detection, the concept of individual protection, the concept of firefighting, the concept of search and rescue, the concept of first aid transfer of personnel, the concept of spill source control and the concept of spill substance control respectively. The ontology class of emergency knowledge for shipboard hazardous cargo incidents is shown in Figure 2.

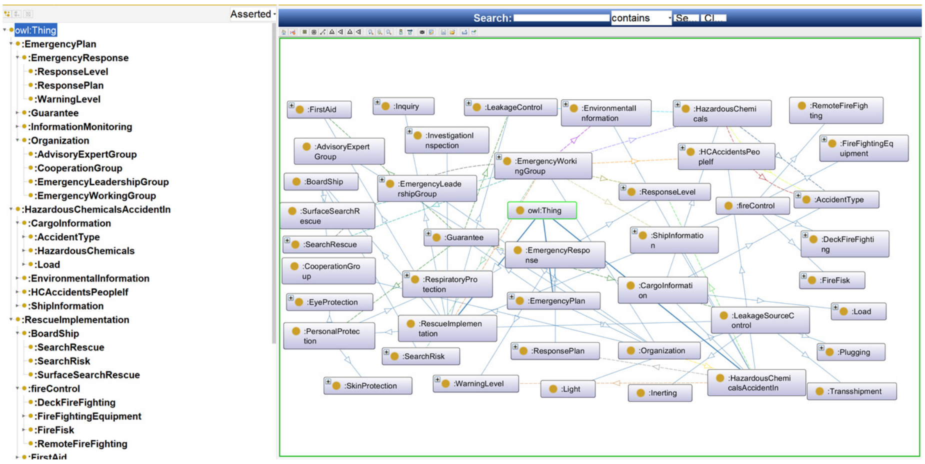


Figure 2 The ontology class of emergency knowledge for shipboard hazardous cargo incidents

2.2 Conceptual relationships for emergency relief

Semantic relations (R) for an emergency response to shipboard hazardous cargo incidents represent the relationships between emergency knowledge. These include ontology generic semantic relationships ($R_{ontology}$) and custom semantic relationships ($R_{factual}$).

$$R = \{R_{ontology}, R_{factual}\} \quad (12)$$

3. Emergency relief ontology data layer construction

The shipboard hazardous cargo incident response ontology data layer is constructed by adding instance knowledge, instance and instance relationships, and instance-related attributes to the ontology schema layer to enrich the Shipboard Hazardous Cargo Incident Response Ontology data and relationships.

3.1 Physical extraction

The emergency response knowledge of shipboard hazardous cargoes is extracted from MSDS, ICSC, IMDG(EmS Guide), Emergency Response Plan, etc. The UN number, CAS registration number, and Chinese and English names of hazardous cargoes are provided in MSDS and ICSC, and the relevant physical properties, chemical properties, and toxicological properties of hazardous chemicals are described. The emergency response entity extracts examples of relevant plans; the emergency resources entity extracts include equipment resources, expert resources, etc. The rescue measures entity extraction includes fire survey, ship floating state, burning area, cooling area, etc.

3.2 Relationship Extraction

The extraction of relationships at the data level of the Shipboard Hazardous Cargo Incident Response Ontology is for instance-to-instance relationships. Concept-to-concept relationships are introduced in the schema layer artifacts, instances are added under the corresponding concepts, and the corresponding instance-to-instance relationships inherit the above relationships.

3.3 Attribute Extraction

The implementation of emergency measures for shipboard hazardous cargo accidents is extremely relevant to the properties of hazardous chemicals, for example, different hazardous chemicals have different densities and solubility leading to different ways of controlling their leaks, different hazardous chemicals have different toxicities, flammability, etc., and individual protective equipment choices vary greatly. According to the MSDS and ICSC, the physical properties of dangerous goods include density to water, density to air, ignition temperature, flash point, ignition point, etc.

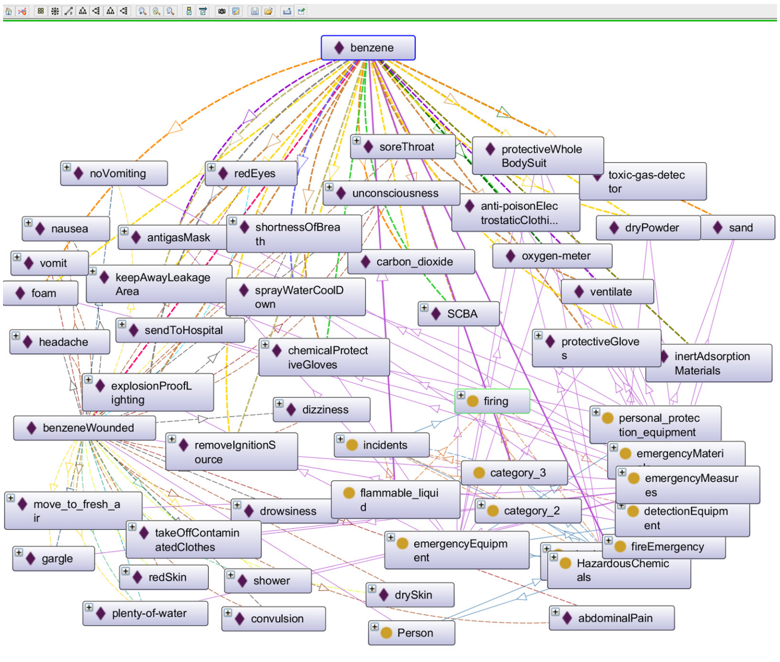


Figure 3 Structured partial diagram of emergency knowledge for shipboard hazardous cargo incidents

Different data attributes have different data types, and the value range of each attribute needs to be limited. Structured partial diagram of the emergency knowledge of shipboard dangerous goods is shown in Figure 3.

4. Ontology mapping algorithm for shipboard hazardous cargo incidents

The shipboard hazardous cargo accident ontology mapping algorithm, based on ontology similarity, is implemented by building a local inter-ontology mapping of shipboard hazardous cargo accidents, even if the distribution and structure of ontology knowledge sources are not understood, and after inputting query statements, a matching set is obtained to achieve the fusion and retrieval of multi-source knowledge. The ontology similarity is an index describing the semantic matching degree among ontologies of the knowledge base, including ontology description similarity, ontology attribute similarity, and ontology structure similarity, and the three are weighted to obtain the comprehensive ontology similarity.

$$\mathrm{Ont}(C_{\mathrm{HCER}i},C_{\mathrm{HCER}j})=\begin{cases}\theta_1\mathrm{OntNam}(C_{\mathrm{HCER}i},C_{\mathrm{HCER}j})+\theta_2\mathrm{OntAtt}(C_{\mathrm{HCER}i},C_{\mathrm{HCER}j})+\theta_3\mathrm{OntStru}(C_{\mathrm{HCER}i},C_{\mathrm{HCER}j})\\ \sum\theta_i=1\ ,\ \ \theta_i\geq 0\end{cases} \tag{13}$$

$\mathrm{Ont}(C_{HCERi}, C_{HCERj})$ denotes ontology composite similarity, $\mathrm{OntNam}(C_{HCERi}, C_{HCERj})$ denotes ontology description similarity, $\mathrm{OntAtt}(C_{HCERi}, C_{HCERj})$ denotes ontology attribute similarity, and $\mathrm{OnStru}(C_{HCERi}, C_{HCERj})$ denotes ontology structure similarity.

Let the names of ontologies C_{HCERi} and C_{HCERj} be str_i and str_j, respectively, and weigh the naming similarity $\mathrm{WeigStr}(str_i,str_j)$ and lexical similarity $\mathrm{WeigSen}(str_i,str_j)$ to obtain the ontology description similarity $\mathrm{OntNam}(C_{HCERi}, C_{HCERj})$.

$$\mathrm{OntNam}(C_{\mathrm{HCER}i},C_{\mathrm{HCER}j})=\alpha\mathrm{WeigStr}(\mathrm{str}_i,\mathrm{str}_j)+(1-\alpha)\ \mathrm{WordSen}(\mathrm{str}_i,\mathrm{str}_j) \tag{14}$$

$$\mathrm{WeigStr}(\mathrm{str}_i,\mathrm{str}_j)=\frac{2\sum_n len(Com\mathrm{str}_n)}{len(\mathrm{str}_i)+len(\mathrm{str}_j)} \tag{15}$$

$$\mathrm{WordSen}(\mathrm{str}_i,\mathrm{str}_j)=\max\left(\frac{2\log node(w)}{\log node(w_i)+\log node(w_j)}\right) \tag{16}$$

len(Comstrn) denotes the length of the nth common substring; $len(str_i)$ and $len(str_j)$ are the lengths of str_i and str_j; SynWord is a standard synonym set, where words in the set are connected by semantic relations; W, W_i, and W_j denote the lexical nodes of the synonym set SynWord; W is the parent node of W_i, W_j, and words str_i, str_j are located on W_i, W_j respectively; node(w) denotes the number of words in node and its children. $\mathrm{WeigSen}(str_i,str_j)$is the maximum value of the similarity of the synonym set of words str_i and story, where α is the weight value, indicating the degree of influence of string similarity on the similarity of ontology names.

The ontology attribute similarity $\mathrm{OntAtt}(C_{HCERi}, C_{HCERj})$, ontology structure similarity $\mathrm{OntStru}(C_{HCERi}, C_{HCERj})$, and ontology name similarity algorithms are similar. $\mathrm{DatAtt}(C_{HCERi}, C_{HCERj})$, and $\mathrm{ObjAtt}(C_{HCERi}, C_{HCERj})$ denote data attribute similarity and object attribute similarity respectively; where β is the weight, indicating the degree of influence of the attribute type on the attribute. OntFat, OntBro, and OntSon denote the similarity of parent, sibling, and child ontologies of ontology C_{HCERi} and ontology C_{HCERj}, and denote the weights.

$$\mathrm{OntAtt}(C_{HCER\,i}, C_{HCER\,j}) = \beta Dat\mathrm{Att}(C_{HCER\,i}, C_{HCER\,j}) + (1-\beta)\ \mathrm{ObjAtt}(C_{HCER\,i}, C_{HCER\,j}) \tag{17}$$

$$\mathrm{OntStru}(C_{HCER\,i}, C_{HCER\,j}) = \begin{cases} \gamma \mathrm{Ont}Fat(C_{HCER\,i}, C_{HCER\,j}) + \lambda \mathrm{OntB}ro(C_{HCER\,i}, C_{HCER\,j}) + \eta \mathrm{Ont}Son(C_{HCER\,i}, C_{HCER\,j}) \\ \gamma + \lambda + \eta = 1\ ,\ \gamma、\lambda、\eta \geq 0 \end{cases} \tag{18}$$

To verify the reasonableness of the ontology knowledge fusion algorithm for shipboard hazardous cargo accidents, the initial reconnaissance monitoring of the collision between the Shanghai "8-20" vessel "Longqing 1" and the "Ninggaopeng 688" was carried out. The ontology mapping algorithm is used to calculate the full similarity of the subclasses, taking "emergency plan - information monitoring - information content" and "rescue measures - detection - dynamic report" as examples. The ontology description similarity OntNam(C_{HCERi}, C_{HCERj}) = 0.88 is calculated according to Eq. (15) and Eq. (16); the ontology attribute similarity OntAtt(C_{HCERi}, C_{HCERj}) = 0.78 is calculated according to Eq. (17); the ontology structure similarity OntStru(C_{HCERi}, C_{HCERj}) = 0.82 is calculated according to Eq. (18); and the ontology comprehensive similarity Ont(C_{HCERi}, C_{HCERj})= 0.83 is calculated. The results show that the "emergency monitoring information" and "rescue detection dynamic report" have 83% similarity, which means that the two different concepts have the same information, therefore, the "monitoring information" can be locked in the rescue implementation ontology, to provide direction for the next rescue. This provides direction for the next step.

5. Conclusion

This paper constructs an ontology for shipboard hazardous cargo accident emergency response, structuring the knowledge expression of unstructured multi-source waterborne hazardous chemical accident information, ensuring the expression of a complex knowledge structure system while correlating the expression of complex emergency rescue knowledge, and at the same time proposing a series of calculation methods for the comprehensive similarity of the ontology to achieve the integration of shipboard hazardous cargo accident emergency response knowledge, further transforming the existing accident information advantages into decision-making advantages, effectively enhancing the content and form of emergency rescue, and providing decision-makers and emergency responders with timely and creative risk resolution, which is of great significance for enhancing waterborne accident emergency response capabilities and improving waterborne accident emergency management.

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