Emerald Insight

Kybernetes

Ontology-based representation of meteorological disaster system and its application in emergency management: Illustration with a simulation case study of comprehensive risk assessment

Fushen Zhang Shaobo Zhong Simin Yao Chaolin Wang Quanyi Huang

Article information:

To cite this document:
Fushen Zhang Shaobo Zhong Simin Yao Chaolin Wang Quanyi Huang , (2016),"Ontology-based representation of meteorological disaster system and its application in emergency management", Kybernetes, Vol. 45 Iss 5 pp. 798 - 814
Permanent link to this document:
http://dx.doi.org/10.1108/K-10-2014-0205

Downloaded on: 14 November 2016, At: 21:45 (PT)
References: this document contains references to 42 other documents.
To copy this document: permissions@emeraldinsight.com
The fulltext of this document has been downloaded 74 times since 2016*

Users who downloaded this article also downloaded:

(2016),"RFM approach for telecom insolvency modeling", Kybernetes, Vol. 45 Iss 5 pp. 815-827 http://dx.doi.org/10.1108/K-04-2015-0113

(2016),"Offering a hybrid approach of data mining to predict the customer churn based on bagging and boosting methods", Kybernetes, Vol. 45 Iss 5 pp. 732-743 http://dx.doi.org/10.1108/K-07-2015-0172

Access to this document was granted through an Emerald subscription provided by emerald-srm:563821 []

For Authors

If you would like to write for this, or any other Emerald publication, then please use our Emerald for Authors service information about how to choose which publication to write for and submission guidelines are available for all. Please visit www.emeraldinsight.com/authors for more information.

About Emerald www.emeraldinsight.com

Emerald is a global publisher linking research and practice to the benefit of society. The company manages a portfolio of more than 290 journals and over 2,350 books and book series volumes, as well as providing an extensive range of online products and additional customer resources and services.

Emerald is both COUNTER 4 and TRANSFER compliant. The organization is a partner of the Committee on Publication Ethics (COPE) and also works with Portico and the LOCKSS initiative for digital archive preservation.

*Related content and download information correct at time of download.

Downloaded by TASHKENT UNIVERSITY OF INFORMATION TECHNOLOGIES At 21:45 14 November 2016 (PT)

The current issue and full text archive of this journal is available on Emerald Insight at:
www.emeraldinsight.com/0368-492X.htm

Ontology-based representation of meteorological disaster system and its application in emergency management

Illustration with a simulation case study of comprehensive risk assessment

Fushen Zhang
Tsinghua University, Beijing, China, and
Shaobo Zhong, Simin Yao, Chaolin Wang and Quanyi Huang
Department of Engineering Physics, Tsinghua University, Beijing, China

Abstract

Purpose – The purpose of this paper is to make research on causing mechanism of meteorological disaster as well as the components of meteorological disaster system and their semantic relationships. It has important practical significance due to the urgent need of further providing support for pre-assessment of influences of disastrous weather/climate events and promoting the level of emergency management.
Design/methodology/approach – This paper analyses the occurrence regulations and components of meteorological disasters and proposes the concept of meta-action. Ontology modelling method is adopted to describe the components and relationships among different parts comprising meteorological disaster system, and semantic web rule language is selected to identify the implicit relationships among the domain knowledge explicitly defined in ontology model. Besides, a case is studied to elaborate how to provide logic and semantic information support for comprehensive risk assessment of disastrous weather/climate events based on rule-based ontology reasoning method. It proves that ontology modelling and reasoning method is effective in providing decision makings.
Findings – This paper provides deep analyses about causing mechanisms of meteorological disasters, and implements information fusion of the components of meteorological disaster system and acquisition of potential semantic relations among ontology components and their individuals.
Originality/value – In this paper, on the basis of analysing the disaster-causing mechanisms, the meteorological disaster ontology (MDO) model is proposed by using the ontology modelling and reasoning method. MDO can be applied to provide decision makings for meteorological departments.

Keywords Emergency management, Meteorological disaster, Ontology-based modelling, Rule-based reasoning
Paper type Research paper

1. Introduction

In recent decades, disastrous weather/climate events occur frequently worldwide thanks to global climate change, urbanization, etc., weather/climate events are caused by meteorological activities such as temperature increase/decrease, rainfall, atmospheric motion, and so on. If these activities are extreme (significantly different from a normal level), disastrous weather/climate events will appear. Disastrous weather/climate events do not necessarily mean meteorological disasters. Only when the disastrous weather/climate events adversely affect areas where some valued objects (including human, building, farmland, infrastructure etc.) exist, meteorological disasters are caused.

Kybernetes
Vol. 45 No. 5, 2016
pp. 798-814
© Emerald Group Publishing Limited
0368-492X
DOI 10.1108/K-10-2014-0205

Figure 1 shows the relationships of meteorological events (meteorological factor activities), disastrous weather/climate events, and meteorological disasters.

In the above sentences, "weather" is for a short time period (e.g. several days) while "climate" is for a long time period (e.g. several years). Disastrous weather/climate events and the secondary/derived ones have been threatening our life, property, and environment, and as a result, seriously hindered economic and social development. Such events can be unconventional and complex. Therefore, the critical problems that researchers and governments at all levels are faced with are how to: precisely integrate and express data on such events; extract logical and semantic information for decision making; and strengthen emergency management of these events.

Domain knowledge is a major determinant for constructing an accurate decision-making support model (Josefa *et al.*, 2001), and the sharing of such knowledge would help improve the entire emergency response process. As for meteorological disasters, generating, interpreting, and deploying knowledge from multiple sources are key factors to improve capability of prevention and response of meteorological disasters. Therefore, developing suitable decision-making support systems for emergency management is necessary. Recently, research on rule-based reasoning systems has become popular, and some techniques are able to reason the semantic relationships among the elements of the domain knowledge according to predefined rules. Many researchers and designers have developed rule-based reasoning systems to support decision making for concrete tasks (Chan and Ip, 2011; Doumpos and Zopounidis, 2010; Kozan and Liu, 2012; Milea *et al.*, 2013; Zhang and Liu, 2002; Thompson *et al.*, 2006; Prentzas and Hatzilygeroudis, 2007; Rodríguez *et al.*, 2012; Nalepa and Bobek, 2014; Vitoriano *et al.*, 2015). A properly designed rule-based reasoning engine is an interactive software-based system intended to help decision makers acquire useful information from raw data, documents, and personal knowledge to solve complicated problems and concrete tasks. However, the domain knowledge of meteorological disasters is heterogeneous, and this can lead to a misunderstanding among different decision makers. To facilitate collaborative and dynamic decision support for prevention and response of a disastrous weather/climate event, it is essential to provide a shared domain knowledge framework of meteorological disasters that enables decision makers to clearly articulate the basic components of meteorological disasters and their semantic relationships.

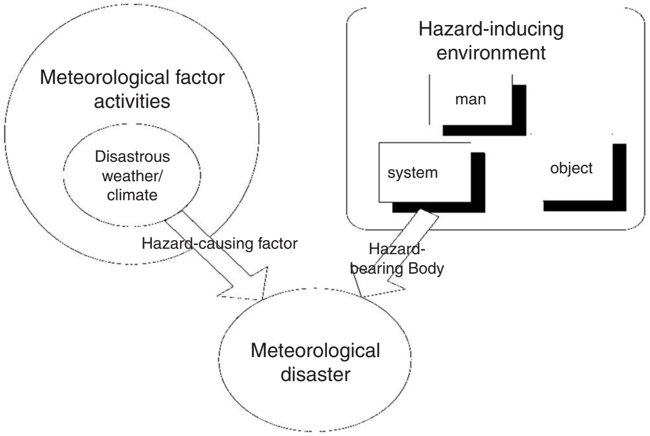


Figure 1.
An illustration of the relationships of meteorological events (meteorological factor activities), disastrous weather/climate events, and meteorological disasters

With respect to the current ontology framework for disasters and rule-based reasoning engines for decision making, one main research areas are less considered. Many traditional systems have only concentrated on knowledge expression of components of disasters, such as studies on hazard bearing bodies (HBBs) and hazard-inducing environments (HIEs). Little attention has been paid to considering the inherent semantic relationships between components of disasters in time and space simultaneously, which could increase the independence and stability.

In the present study, we propose a knowledge sharing model for meteorological disasters, called MDO, which enables a systematic description of the components of meteorological disasters and implies some relationships and rules among them. And then this model is supposed to provide logic semantic knowledge, which is easily ignored but generally plays important role in decision making for emergency management activities. Our goal is to help decision makers make timely decisions during both routine and urgent situations.

We present our work in four steps. First, we analyse the structure of disastrous meteorological event. Second, the MDO model is established by Protégé, a popular, open-source platform. Third, the reasoning function for decision making is achieved by predefining appropriate decision rules, implicit decision information, and some potential semantic relations between the components of ontology. Fourth, an illustration to the role of the model in emergency management is presented through a simulation case study of comprehensive risk assessment of disastrous weather/climate events (Figure 2).

The remainder of this paper is organized as follows: Section 2 reviews the relevant literature. Section 3 briefly illustrates domain knowledge of the meteorological disaster system. Section 4 introduces the methodology of constructing the MDO and rule-based ontology reasoning methods. Section 5 illustrates the proposed approaches through a simulation case study of comprehensive risk assessment of disastrous weather/climate events, and Section 6 concludes the paper and presents some suggestions for future work.

2. Literature review

In recent years, ontology modelling and rule-based reasoning methods have been widely used to solve specific modelling and decision support problems in emergency management. Around the purpose of this paper, we review the research status from two aspects: ontology modelling in emergency management and emergency decision support system.

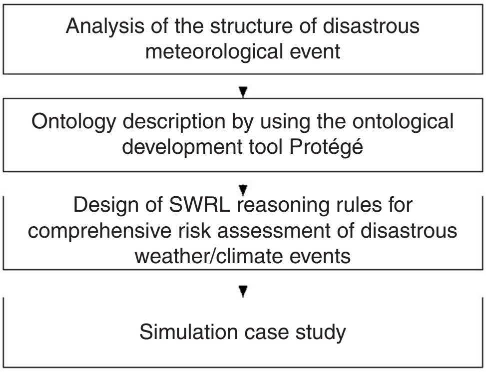


Figure 2.
Research framework of this study

2.1 Ontology modelling in emergency management

In most research work, ontology modelling is employed to identify concepts, categories, relations, and rules, thereby defining and conceptualizing the knowledge in a specific domain to make it easier to build a model; this can facilitate other tasks such as knowledge engineering, database design, information modelling, and information inquiry (Agarwal, 2005; Guarino, 1999). Recently, ontology has been widely used in emergency management to provide logic semantic rules for decision analysis. For example, Liu *et al.* (2012) defined the concepts, properties, instances, and relationships of the ontology in the area of the natural disaster emergency logistics and solve the problem of knowledge sharing and information integration. Araujo *et al.* (2008) describes an architecture to support nonprogrammer emergency management trainers to rapidly create different instances of powerful and complex training simulations. Galton and Worboys (2011) describes some work on the ontology of information that can contribute to a solution of the integration problem in order that the Common Operating Picture can truly and effectively provide the unified view required of it. Wang *et al.* (2005, 2006, 2009) use an ontology of emergency knowledge to formalize the logic and semantics of emergency plan and emergency response process, in which ontology is used to provide an effective means to implement semantic-level integration. Sotoodeh (2007) constructed the emergency management ontology model and defined the relationships among some critical ontology concepts including emergency, infrastructure, region/population, and collaboration. Some scholars have constructed other domain ontologies. Hung *et al.* (2004) developed a plan ontology that can capture the knowledge found in the domain of military planning organizations, tasks, and relations such as task assignment.

In more recent years, geo-ontology is put forward by some researchers from geographic information science domain. Geo-ontology is a very complex and intricate concept that mainly refers to studying geographic objects, concepts, categories, and relations, which extends ontology to a geographic context (space-time context). Little and Rogova (2005) designed a general methodology for situation assessment to support crisis management. Xu *et al.* (2014) put forward a conceptual model of knowledge for earthquake disaster emergency response (EDER), where geo-ontology serves to represent geospatial characteristics of the EDER knowledge and addresses a need for semantic interoperability in the modelling process.

In implementation of ontology, a number of programming languages and standards are widely used, including Resource Description Framework Schema, Web Ontology Language, DAML + OIL (DAML: DARPA agent markup language, OIL: ontology inference layer), and semantic web rule language (SWRL).

2.2 Decision support system for emergency management

The threat of disasters has reaffirmed the urgency and importance of decision support systems as well as the need to pre-assess those disasters. These tasks include routine and urgent ones. The former refers to some pre-disaster work such as safety planning, risk assessment, and resource preparedness while the latter generally means post-disaster response. Chen *et al.* (2008) presents a method to integrate GIS and computational models in emergency intelligent decision support system where disaster evolution prediction, impact areas demarcation, human behaviour simulation and real-time data acquisition were integrated and considered in a correlative manner. Fogli *et al.* proposed a novel knowledge-centred design methodology and demonstrated its application through a concrete case study in the field of pandemic flu emergency management. Amailef and Lu (2013) presents an emergency response system ontology-supported case-based reasoning method, with implementation, to support emergency decision makers to effectively respond to emergencies. Vivacqua and Borges (2012) consider the domain of emergency response, harness collective knowledge for emergency management and present architecture and examples of how this could be accomplished. Yong *et al.* (2001) introduced a web-based decision support tool called extremum that may be applied to risk and loss assessment by end-users. It can provide operative information on damage and casualties due to strong earthquakes all over the world. Balducelli *et al.* (2000) adopted a decision support system call the intelligent decision assistant (IDA), which can play an important role in emergency management of a large area based on agent technology. The system consists of three software agents: a direct advisor, automatic planner, and information provider. Gadomski *et al.* (2001) further developed and verified specific IDA objectives using information-managed and knowledge-managed agents. Cuena and Ossowski (2000) presented the design and development of multi-agent and distributed artificial intelligence systems.

3. Domain knowledge of meteorological disasters

3.1 Meteorological disaster system

The domain knowledge of meteorological disasters is analysed through exploring the process of formation, occurrence, and development of a meteorological disaster. The evolving process of disastrous weather/climate events follows a typical spatiotemporal evolution process. In the process, there are three components which contribute to the meteorological disaster: meteorological factors, disastrous weather/climate events, HBBs, HIEs. We will investigate the concepts and relationship, and formulate the rules among the three components. Here, we propose so-called meta-actions (the common actions or effects causing a variety of disastrous weather/climate events). And then, the MDO modelling of representing the domain knowledge will be introduced in Section 4.

To explain the following MDO model, we first propose a structure of meteorological disaster system, which is composed of three components and their relationships. The relationships between these components can be categorized into four types: *Time_R*, *Spatial_R*, *Functional_R*, *Other_R*. *Time_R* represents timing relations (e.g. before, after, concurrent, etc.) between different disastrous weather/climate events, *Spatial_R* represents spatial relations (e.g. topology, distance, orientation, etc.) between different HBBs, *Functional_R* represents the functional relations (e.g. addition, subtraction, multiplication, division, etc.) between different components, and *Other_R* represents other relations in the structure besides the first three types. Figure 3 is an illustration of meteorological disaster system.

3.2 Set representation for meteorological disaster system

In a meteorological disaster, which HBBs are affected and how they are affected depend on the disaster-formative factors, the HIE, and the properties of the HBBs. We use Set tool defined as follows to describe these concepts:

$$\begin{cases} M = \langle M_e, M_p, R \rangle \\ M_e = \{H_b, D_f, H_e, \Lambda, M_f\} \\ M_p = \{\Psi, \Phi\} \\ \Lambda = \{\lambda_i | i = 1, 2, \ \ldots, \ 11\} \end{cases} \tag{1}$$

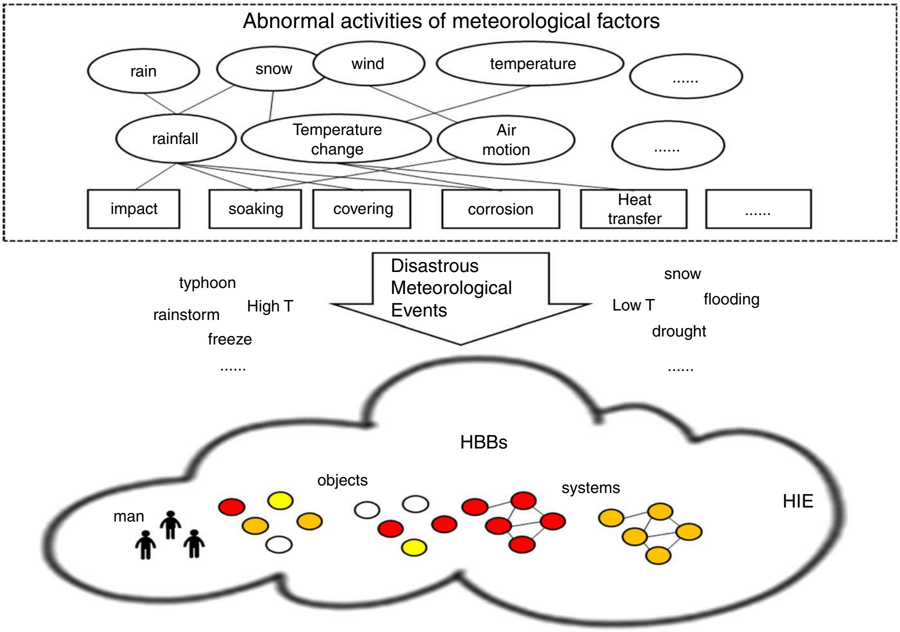


Figure 3. An illustration of meteorological disaster system

where M represents meteorological disasters, M_e is a set of components for such a disaster, M_p is an attribute set for the components, R is a set of relationships between the components, H_b is a set of HBBs, D_f is a set of disaster-formative factors, H_e is a set of HIEs, Λ is a set of meta-actions, λ_i are meta-actions (there are 11 kinds of meta-actions causing various disastrous weather/climate events from our study), and M_f is a set of meteorological factors.

To create a semantic network connecting different classes and describing their characteristics, properties need to be carefully defined. Ψ represents the object properties of the components of a meteorological disaster system. The object property defines the relationships between two objects, and it works as a bridge linking two individuals from different parts of the class hierarchy. Φ represents the data property, which acts more like the innate attribute of an object, and describes relationships between individuals and data values.

3.3 Meta-actions between meteorological factors and HBBs

There are some intrinsic mechanisms that determine whether a given HBB will be affected by a disastrous weather/climate event and by which meta-actions it would be affected. For example, static pressure can be viewed as the added gravitational pull of water, snow, or ice on an HBB (in terms of added weight), and the degree of the effect depends on the qualities of that water, snow, or ice. Building on the "emergency meta-actions", the present paper provides the typical modes of action (hereafter, action forms) of meta-actions caused by various disastrous weather/climate events. Some generally seen meta-actions include impact, static pressure, soaking, electric shock, covering, heat transfer, blinding, corrosion, electromagnetic interference, contamination, and entrainment. The explanations of them are shown in Table I.

Table I.
Meta-actions and their action forms

Meta-actions	Forms	Examples
Impact	Water crashes into an HBB (being hit by force)	Flooding washes out bridges, houses, and other buildings
Static pressure	Static pressure, caused by the pull of gravity, destroys the structure of an HBB, thus affecting its function	In an ice storm, the snow and ice cause a buildup of static pressure on houses, buildings, or crops
Soaking	An HBB becomes immersed in liquid	Houses are destroyed or collapse by water immersion in a flood
Electric shock	An HBB is hit by lightning, and its structure and/or function are damaged	In lightning storms, electroshock can lead to human and animal disability or death
Covering	An HBB is covered up or blanketed	Humans or animals are covered by snow or floods, which leads to death. In continuous heavy rain, surface water leads to roads that are slippery
Heat transfer	Heat flows from the warmer to the cooler body or flows from the warmer to the cooler part of an object	With freezing damage, humans or animals are frostbitten; rivers are frozen. In drought, humans and animals can very quickly dehydrate; heat has ripened some crops early
Blinding	Humidity or suspended particles in the air reduce visibility	In a sandstorm, vehicles and pedestrians can get lost or stuck
Corrosion	An HBB is gradually corroded via chemical action	Buildings, communal facilities, and soil are the victims of acid rain
Electromagnetic interference	Electromagnetic noise interferes with electric cables and reduces signal integrity	Lighting interferes with normal communications and transfer of information
Contamination	Lesions or damage can result from an intake of toxic substances	In heavy fog or a sandstorm, people and animals become sick as a result of inhaling toxic particles
Entrainment	Suction results from the pressure difference in the air by convection	Cars, boats, and other objects are swept away or roofs are damaged

China meteorological administration categorizes meteorological disasters occurring in the territory into seven categories: flood, drought, typhoon, freezing, windstorm, continuous rainfall, and others. The proposed 11 meta-actions can be mapped to each of these disasters as follows: flood: impact, soaking, covering; drought: heat transfer; typhoon: impact, entrainment; freezing: static pressure, covering, heat transfer; windstorm: electric shock, electromagnetic interference, impact, entrainment, blinding; continuous rainfall: static pressure, soaking, covering; others (dust storm, smog, acid rain, air pollution): blinding, corrosion, and contamination.

We can identify whether some kind of HBBs are affected by a given disastrous weather/climate event given the mapping between meta-actions and disastrous weather/climate events. For instance, when a rainstorm hits, from the mapping we can see some meta-actions such as soaking, covering, blinding, and entrainment are associated with the rainstorm.

4. Ontology description

Many factors contribute to the formation and development of disastrous weather/climate events. For example, disaster duration, the specific properties of the object affected by the disaster, and the environment where the disaster happens all play a significant role. Building MDO is a scientific and effective way to normalize the knowledge base of meteorological disasters. Given the complexity of the meteorological disaster system, to better integrate the domain knowledge, the methodology of constructing ontology is introduced.

In this paper, the building process of MDO is supported by the use of Protégé, a popular, open-source platform that provides users with a suite of tools to construct domain models. It greatly facilitates the definition of classes, properties and restrictions of MDO and supports the visualization and manipulation of the ontology. The rule-based reasoning has been supported by Jess, a user-friendly rule engine for the Java platform. Jess Tab provides a Jess console window where it's convenient to interact with Jess while running protégé. In this part, an 11-step MDO building procedure is applied in the phase of building the MDO which involves the following activities, see Table II.

Figure 4 provides an overview of all classes of MDO, consisting of *Mesh_Compartment*, *Meteorological_Factor*, *Disaster_Formative_Factor*, *Disaster_Causing_Environment*, *Hazard_Bearing_Body* and *Meta-actions*. *Mesh_Compartment* is designed for regional comprehensive risk assessment. *Mesh_Compartment* can be divided into two subclasses, i.e., *Regular_Mesh* (such as dividing the studied area into some squares) and *Irregular_Mesh* (such as dividing the studied area according to administrative regions or by roads). *Hazard_Bearing_Body* can be divided into three classes, i.e., *Point_Hazard_Bearing_Body*, *Line_Hazard_Bearing_Body*, and *Area_Hazard_Bearing_Body* according to the shape of HBB. *Meteorological_Factor* can be divided into four classes, i.e., Wind, Snow, Rain and Temperature. *Disaster_Causing_Environment* can be divided into two classes, i.e., *Social_Environment* and *Natural_Environment*. *Meta-actions* includes *Impact*, *Static_Pressure*, *Soaking*, *Electric_Shock*, *Covering, Heat_Transfer*, *Blinding*, *Corrosion*, *Electromagnetic_Interference*, *Contamination*, *Entrainment*.

5. Rule-based ontology reasoning

In this part, SWRL which expresses rules in a semantic way has been used to acquire the potential relations among the meteorological disaster knowledge defined in MDO. A SWRL reasoning rule includes two parts, i.e. "*antecedent*" and "*consequent*". It can be described as "*antecedent*"→"*consequent*".

The "*antecedent*" expresses some integrated premises before reasoning process and the "*consequent*" shows the result that can be acquired after this process has been fulfilled. Furthermore, "*atom*" is the basic component which appears in an integrated "*antecedent*".

Step 1	Analysis of the existing ontology in the meteorological disaster domain
Step 2	Extraction of the relevant information for the disastrous meteorological events domain
Step 3	Definition of classes' hierarchy based on structure for disastrous meteorological event
Step 4	Definition of data properties to describe classes
Step 5	Definition of object properties to describe the internal structure of concepts
Step 6	Identification of instances and their description
Step 7	Write reasoning rules for emergency disposal of disastrous meteorological events
Step 8	By using the SWRL tab embedded in the Protégé, selected rules are loaded
Step 9	Load the Jess reasoning module in the Protégé, the ontology instances and the SWRL rules will be added to the Jess
Step 10	Perform the reasoning rules
Step 11	Show reasoning results based on protégé and GIS

Table II.
Eleven-step MDO building procedure

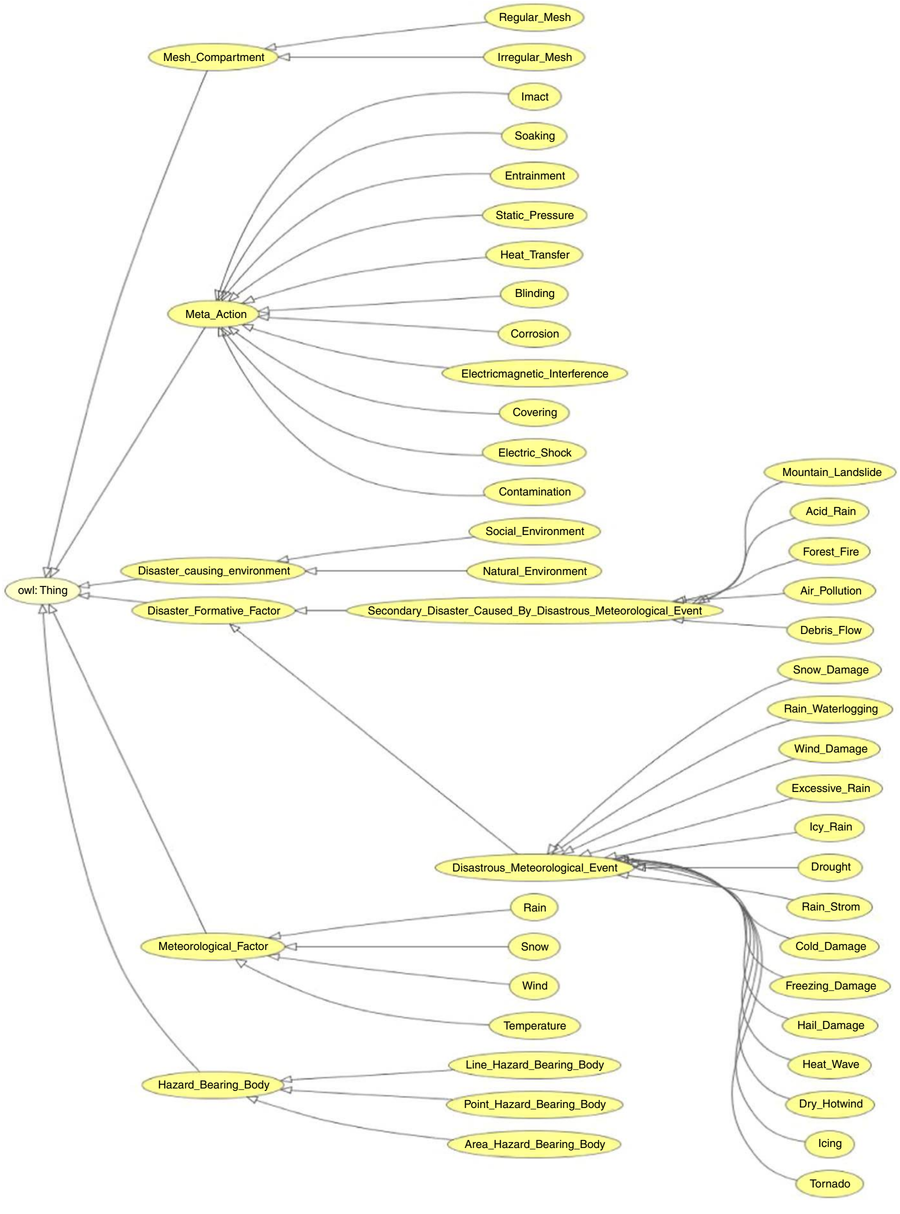


Figure 4.
Overview of all classes defined in MDO

In SWRL, properties and individuals defined in the MDO are applied in "*atom*" clause as the attribute and the parameter of the atom respectively. There are many sorts of atom, but in this section two common atoms in SWRL syntax are used in the reasoning phase of MDO which are introduced as follows:

C(?*x*): if x is an instance of the class *C* or the value of its data property, then *C*(?*x*) holds; *P*(?*x*, ?*y*): if *x* is related to *y* via property *P*, then *P*(?*x*, ?*y*) holds. Here P is the property defined in the existing ontology, x and y can be variables, individuals or the data value. In SWRL syntax, a rule can be described in a form like this: $a_1 \wedge a_2 \wedge a_3 \wedge a_4 \wedge \ldots \wedge a_i \wedge \ldots \wedge a_n \rightarrow b_1$. Atoms a_i and b_i can be either *C*(?*x*) or *P*(?*x*, ?*y*). Generally speaking, there are also some built-ins in the SWRL syntax that is capable of describing the logical comparison relationship. However, since they are not broadly used in this research, no further explanation will be given to this section.

In general, there are also built-in functions in the SWRL syntax that are capable of describing the logical comparison relationship. However, because they are only partially used in this research, they will not be explained here. We have written all rules for some activities of emergency management such as safety planning, integrated risk assessment, prediction of disaster chain, emergency response, and so on. As the length limit, we will only demonstrate some key rules that are used in reasoning for comprehensive risk assessment of disastrous meteorological events.

Five reasoning rules were written for comprehensive risk assessment. Rule 1 is used for calculating the vulnerability of singular HBB. Rule 2 is used for reasoning the ambient severity of HBB in each mesh compartment. Rule 3 is used finding the sum of the vulnerability of singular HBB in a mesh compartment. In addition, the Rule 4 is used for calculating regional restoring force, and the Rule 5 is used to reason the value for the mesh compartment's comprehensive risk (Table III).

6. Simulation case study

We demonstrate how to use MDO to assess the integrated risk by a simulated case. The meteorological disasters that frequently take place in this area have had a negative impact on transportation, industrial production, and daily life. The infrastructure and buildings in

Rule ID	Rule sentence
Rule 1	*Hazard_Bearing_Body(?hbb)∧FunctionalIntegrality_duration(?hbb, ?mfd)∧FunctionalIntegrality_InitialValue(?hbb,?mfi)∧FunctionalIntegrality_TerminalValue (?hbb, ?mft)∧FunctionalIntegrality_Weightiness(?hbb, ?mfw)∧PhysicalRobustness_duration (?hbb, ?mpd)∧PhysicalRobustness_InitialValue(?hbb, ?mpi)∧PhysicalRobustness_TerminalValue (?hbb, ?mpt) ∧ PhysicalRobustness_Weightiness(?hbb, ?mpw) ∧Functionality_ resistance (?hbb, ?rmf)∧Physical_ robustness_ resistance (?hbb, ?rmp) ∧swrlb:subtract(?mfst, ?mft, ?mfi) ∧swrlb: divide(?mfdt, ?mfst, ?mfd)∧swrlb:subtract(?mfss, ?mfdt, ?rmf)∧swrlb:multiply(?mfmt, ?mfss, ?mfw)∧swrlb:subtract(?mpst, ?mpt, ?mpi)∧swrlb:divide(?mpdt, ?mpst, ?mpd)∧swrlb:subtract (?mpss, ?mpdt, ?rmp)∧swrlb:multiply(?mpmt, ?mpss, ?mpw)∧swrlb:add(?mv, ?mfmt, ?mpmt) → Vulnerability_of_singular_ hazard_ bearing_ body (?hbb, ?mv)*
Rule 2	*Hazard_Bearing_Body(?hbb)∧Influence_ degree_of_topography (?hbb, ?edm)∧Influence_degree_of_ geomorphology (?hbb, ?edx)∧swrlb:multiply(?e, ?edm, ?edx)→Ambient_ severity (?hbb, ?e)*
Rule 3	*Mesh_Compartment(?m)∧Hazard_Bearing_Body(?h)∧isPartOf(?h, ?m)∧Integrated_vulnerability_of_ singular_ hazard_ bearing_ body (?h, ?c)→sqwrl:select(?m)∧ sqwrl:sum(?c)*
Rule 4	*Mesh_Compartment(?m)∧MC_Weightiness_1 (?m, ?o1)∧MC_Weightiness¬_2(?m, ?o2)∧MC_Weightiness_3 (?m, ?o3)∧MC_Res(?m, ?res)∧MC_Ep(?m, ?ep) ∧ MC_Reb(?m, ?reb) ∧ swrlb:multiply (?t1, ?o1, ?res) ∧ swrlb:multiply (?t2, ?o2, ?ep) ∧ swrlb:multiply (?t3, ?o3, ?reb) ∧ swrlb:add(?c, ?t1, ?t2, ?t3) → Regional_restoring_force(?m, ?c)*
Rule 5	*Mesh_Compartment(?m)∧MC_H(?m,?h)∧MC_E(?m,?e)∧MC_g(?m,?g)∧MC_V(?m,?v)∧MC_C (?m,?c)∧swrlb:subtract(?tc,1,?c)∧swrlb:multiply(?t1,?e,?g)∧swrlb:multiply(?t2,?t1,?v)∧swrlb: multiply(?t3,?h,?t2)∧swrlb:multiply(?r,?t3,?tc)→MC_ Risk (?m,?r)*

Table III.
Rule sentences for comprehensive risk assessment

this region are used as the HBBs to be assessed. The studied area was divided into ten mesh compartments according to roads. Consistent with the proposed MDO, we perform the risk assessment for these ten mesh compartments affected by the rainstorm disaster using reasoning rules. Figure 5 shows the studied area and its ten mesh divisions.

In this simulated case, the related attributes of the HBBs and the mesh compartments were assigned by the method of random functions. And these functions were designed on the basis of *Rand* (·) in Matlab. Table IV shows these designed random functions for simulated case study.

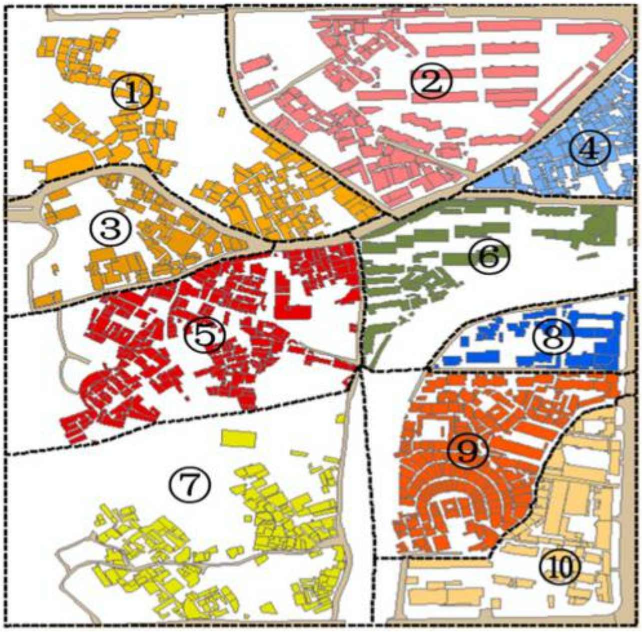


Figure 5.
Studied area and its ten mesh divisions

Table IV.
Designed random functions for simulated case study

Name	Function	Parameter interpretation
Assign_Initial_vulnerability_singleHBB (L_IVS, H_IVS)	Assign the initial vulnerability of each single hazard bearing body	*L_IVS* is the lower limit of the initial vulnerability of single hazard bearing body; *H_IVS* is the upper limit of the initial vulnerability of single hazard bearing body
Hazard_Degree_Mesh(L_HDM, H_ HDM)	Assign the hazard degree of each mesh compartment	*L_HDM* is the lower limit of the hazard degree of each mesh compartment; *H_ HDM* is the upper limit of the hazard degree of each mesh compartment
Restoring_Force_Mesh(L_RFM, H_ RFM)	Assign the restoring force of each mesh compartment	*L_RFM* is the lower limit of the restoring force of each mesh compartment; *H_ RFM* is the upper limit of the restoring force of each mesh compartment

We assumed that the vulnerability of single HBB is changed according to the following formula:

$$v(t) = 1-(1-v_0)e^{-v_0 t} \tag{2}$$

where v_O is the initial vulnerability of single HBB. Formula (1) is able to approximately represent the characteristics of the vulnerability of single HBB varying with time.

Based on the defined random functions in Table IV, we did the following simulation assignment: we assigned the "*H_IV* = 1" and "*L_IVS* = 0.9" in random function "*Assign_Initial_vulnerability_singleHBB(L_IVS, H_IVS)*"; we assigned the "*H_HDM* = *0.9*" and "*L_HDM* = *0.6*" in random function "*Hazard_Degree_Mesh (L_HDM, H_ HDM)*"; and we also assigned the "*H_RFM* = *0.5*" and "*L_RFM* = *0.3*" in random function "*Restoring_Force_Mesh(L_RFM, H_ RFM)*".

The studied area contains a total of 379 HBBs requiring value assignment. Figure 6 shows an example of the building of an ontology individual, i.e., area_hazard_bearing_body_36. We also built ten individuals of class "*Mesh_Compartment*" to represent the ten mesh divisions described in Figure 5, namely, individual "*Mesh_Compartment_1*", individual "*Mesh_Compartment_2*", individual "*Mesh_Compartment_3*", individual "*Mesh_Compartment_4*", individual "*Mesh_Compartment_5*", individual "*Mesh_Compartment_6*", individual "*Mesh_Compartment_7*", individual "*Mesh_Compartment_8*", individual "*Mesh_Compartment_9*" and individual "*Mesh_Compartment_10*".

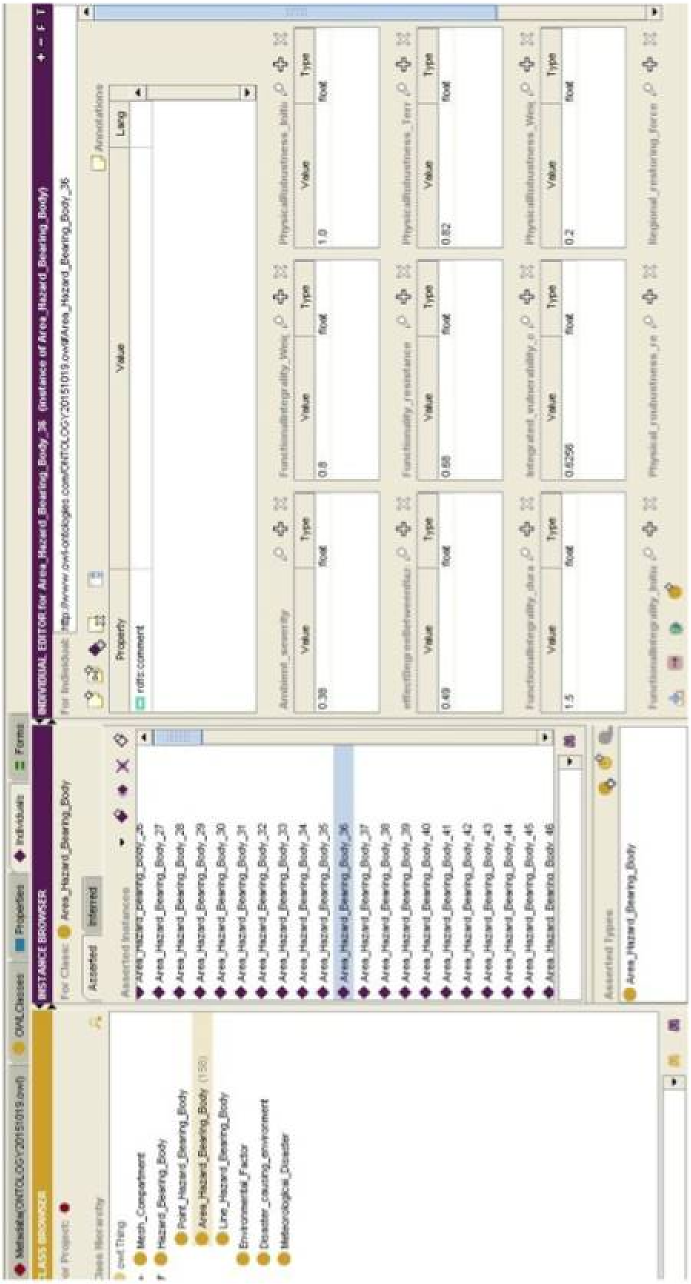
The reasoned results can be saved via OWL RDF/XM format. The saved OWL RDF/XM format reasoning results can then be displayed by inputting into Arc GIS. Figure 7 shows the zoning map of the risk in ten mesh compartments.

The above results show that, through integrated consideration of the constitute elements of comprehensive risk, i.e. "vulnerability of singular hazard bearing body", "hazard of the meteorological events", and "regional restoring force", by using ontology-based modelling and reasoning method, the integrated risk of each mesh compartment can be assessed. In addition, Figure 7 also reflects the dynamic changes of the integrated risk of meteorological disaster (rainstorm).

7. Conclusions and future work

Making research on meteorological disaster-causing mechanism as well as the components of meteorological disaster system and their relations has extremely important practical significance due to the urgent need of further promoting management level of disastrous meteorological events. In this paper, based on analysing the existing relevant research work and disaster-causing mechanism, MDO is developed to describe components of the meteorological disaster. Also, in order to support emergency disposal, SWRL has been adopted to identify the implicit relations among the domain knowledge explicitly defined in MDO. In addition, a simulation case study of a region suffering meteorological disaster(rainstorm in this case) has been introduced in this study to validate the feasibility and effectiveness of the ontology-based approach proposed in this paper. The reasoning results are shown by Arc GIS.

The proposed framework provides a new method for comprehensive risk assessment of mesh division affected by meteorological disaster, and the main advantages are as follows: first, the proposed framework is found to be easy to operate, and the comprehensive risk affected by a specific meteorological disaster can be evaluated, as long as assigning the attributes defined in the ontology model; and second, the comprehensive risk value of each mesh compartment affected by meteorological disasters at different times can be assessed.



For Individual: http://www.owl-ontologies.com/ONTOLOGY20151019.owl#Area_Hazard_Bearing_Body_36

Ambient_severity: 0.38 float

FunctionalIntegrality_Wea: 0.8 float

PhysicalRobustness_Iolu: 1.0 float

effectiong: 0.49 float

Functionality_resistance: 0.88 float

PhysicalRobustness_Terr: 0.82 float

FunctionalIntegrality_dura: 1.5 float

Integrated_vulnerability_c: 0.6256 float

PhysicalRobustness_Wea: 0.2 float

Figure 6.
Example of constructing an ontology individual (area_hazard_bearing_body_36)

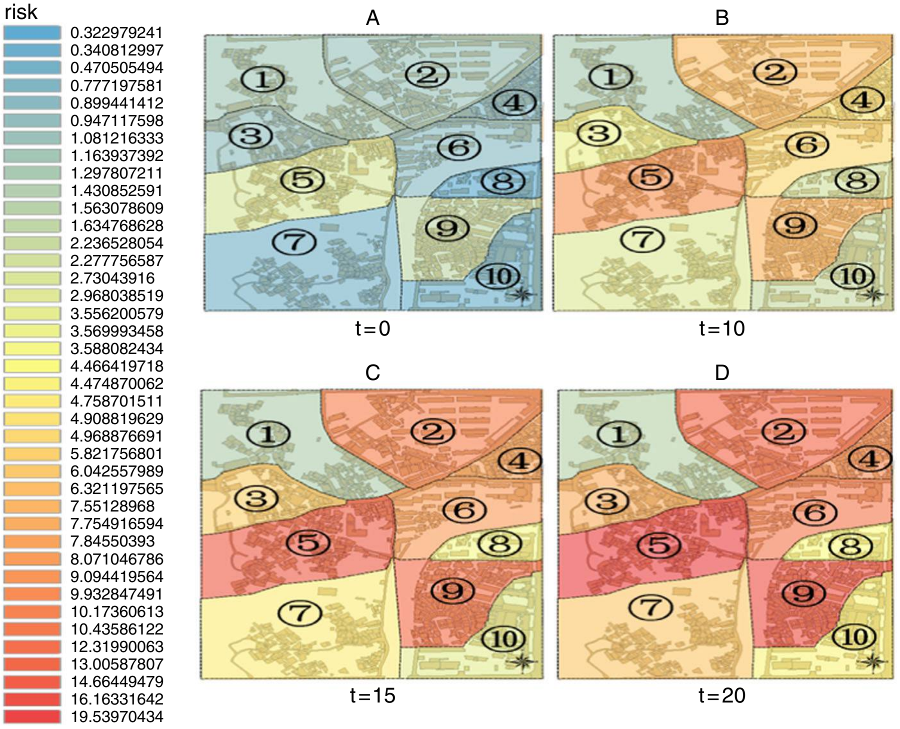


Figure 7.
Zoning map of the risk in ten mesh compartments (i.e. in $t = 0$, 10, 15, and 20 basic time unit)

This study suffers from limitations that should be addressed. First, it only involves preliminary ideas and results, and must be improved and supplemented in more applications with verification and development. In addition, on the basis of the proposed framework in this paper, the identification standard of HBB's vulnerability after meteorological disasters should be further designed for performing more scientific and accurate risk assessment of each mesh division.

Acknowledgements

The authors would like to thank the support of the National Natural Science Foundation of China (Study on Pre-qualification Theory and Method for Influences of Disastrous Meteorological Events, Grant No. 91224004), the youth talent plan programme of Beijing City College (Study on Semantic Information Retrieval of Decision Analysis of Emergency Management for Typical Disastrous Meteorological Events, Grant No. YETP0117), the Project in the National Science & Technology Pillar Programme during the Twelfth Five-year Plan Period (Study and Demonstration of Key Technology of Safe Operation and Emergency Response of Towns, Grant No. 2015BAK12B03).

References

Agarwal, P. (2005), "Ontological considerations in GIS science", *International Journal of Geographical Information Science*, Vol. 19 No. 5, pp. 501-536.

Amailef, K. and Lu, J. (2013), "Ontology-supported case-based reasoning approach for intelligent m-government emergency response services", *Decision Support Systems*, Vol. 55 No. 1, pp. 79-97.

Araujo, R.B., Rocha, R.V., Campos, M.R. *et al.* (2008), "Creating emergency management training simulations through ontologies integration[C]", *Computational Science and Engineering Workshops (CSEWORKSHOPS'08), 11th IEEE International Conference on IEEE*, pp. 373-378.

Balducelli, C., Costanzo, G.D. and Gadomski, A.M. (2000), "A prototype of an active decision support system for automatic planning support in emergency management", presented at Seventh Annual Conference of the International Emergency Management Society (TIEMS 2000), Orlando, FL.

Chan, S.L. and Ip, W.H. (2011), "A dynamic decision support system to predict the value of customer for new product development", *Decision Support System*, Vol. 52 No. 1, pp. 178-188.

Chen, T., Yuan, H.Y., Yang, R. and Jianguo, C. (2008), "Integration of GIS and computational models for emergency management", *International Conference on Intelligent Computation Technology and Automation (ICICTA), IEEE, Vol. 2*, pp. 255-258.

Cuena, J. and Ossowski, S. (2000), *Multiagent Systems: A Modern Approach to Distributed AI*, The MIT Press, Cambridge, MA.

Doumpos, M. and Zopounidis, C. (2010), "A multi-criteria decision support system for bank rating", *Decision Support System*, Vol. 50 No. 1, pp. 55-63.

Gadomski, A.M., Bologna, S., Costanzo, G.D., Perini, A. and Schaerf, M. (2001), "Towards intelligent decision support systems for emergency managers: the IDA approach", *International Journal of Risk Assessment and Management*, Vol. 2, pp. 224-242.

Galton, A. and Worboys, M. (2011), "An ontology of information for emergency management", *Proceedings of 8th International Conference on Information Systems for Crisis Response and Management*, pp. 1-10.

Guarino, N., Masolo, C. and Vetere, G. (1999), "Ontoseek: content-based access to the web", *Intelligent Systems and Their Applications, IEEE*, Vol. 14 No. 3, pp. 70-80.

Hung, L.C., Beng, L.H., Wah, N. G. and Yin, H.K. (2004), "Plan ontology and its application", *7th International Conference on Information Fusion, JAIF, Stockholm*, pp. 455-460.

Josefa, Z., Hernandez, J. and Serrano, M. (2001), "Knowledge-based models for emergency management systems", *Expert Systems with Applications*, Vol. 20 No. 14, pp. 173-186.

Kozan, E. and Liu, S.Q. (2012), "A demand-responsive decision support system for coal transportation", *Decision Support Systems*, Vol. 54 No. 1, pp. 665-680.

Little, E.G. and Rogova, G.L. (2005), "Ontology meta-model for building a situational picture of catastrophic events", presented at 2005 8th International Conference on Information Fusion, Philadelphia, PA, 25-28 July.

Liu, C., Deng, S., Yang, X. and Huang, Y. (2012), "Knowledge representation in the field of natural disaster emergency logistics based on ontology", *International Journal of Advancements in Computing Technology*, Vol. 4 No. 13.

Milea, V., Fransincar, F. and Keymak, U. (2013), "A general framework for time-aware decision support systems", *Expert Systems with Applications*, Vol. 40 No. 2, pp. 399-407.

Nalepa, G.J. and Bobek, S. (2014), "Rule-based solution for context-aware reasoning on mobile devices", *Computer Science and Information Systems*, Vol. 11 No. 1, pp. 171-193.

Prentzas, J. and Hatzilygeroudis, I. (2007), "Categorizing approaches combining rule based and case based reasoning", *Expert Systems*, Vol. 24 No. 2, pp. 97-122.

Rodríguez, J.T., Vitoriano, B. and Montero, J. (2012), "A general methodology for data-based rule building and its application to natural disaster management", *Computers & Operations Research*, Vol. 39 No. 4, pp. 863-873.

Sotoodeh, M. (2007), *Ontology-Based Semantic Interoperability in Emergency Management*, Vol. 7, The University of British Columbia.

Thompson, S., Altay, N., Green, W.G. III and Lapetina, J. (2006), "Improving disaster response efforts with decision support systems", *International Journal of Emergency Management*, Vol. 3 No. 4, pp. 250-263.

Vitoriano, B., Rodríguez, J.T., Tirado, G., Martín-Campo, F.J., Ortuño, M.T. and Montero, J. (2015), "Intelligent decision-making models for disaster management", *Human and Ecological Risk Assessment: An International Journal*, Vol. 21 No. 5, pp. 1341-1360.

Vivacqua, A.S. and Borges, M.R.S. (2012), "Taking advantage of collective knowledge in emergency response systems", *Journal of Network and Computer Applications*, Vol. 35 No. 1, pp. 189-198.

Wang, W., Dong, C. and Yang, P. (2009), "Ontology modeling of emergency plan systems", *Sixth International Conference on Fuzzy Systems and Knowledge Discovery, FSKD'09, IEEE*, *Vol. 2*, pp. 290-294.

Wang, W., Liu, X., Luo, Y., Wang, X., and Xu, Z. (2005), "Study of ontology and application for emergency event model", *Computer Engineering*, Vol. 31 No. 10, pp. P10-P12.

Wang, W., Meng, F., Wang, Y., Luo, Y. and Xu, Z. (2006), "Research on ontology-based emergency response plan template", *Computer Engineering*, Vol. 32 No. 19, pp. 170-172.

Yong, C., Chen, Q.F., Frolova, N., Larionov, V., Nikolaev, A., Pejcoch, J. and Ugarov, A. (2001), "Web based decision support tool in order to response to strong earthquakes", presented at TIEMS2001, Oslo.

Xu, J., Nyerges, T.L. and Nie, G. (2014), "Modeling and representation for earthquake emergency response knowledge: perspective for working with geo-ontology", *International Journal of Geographical Information Science*, Vol. 28 No. 1, pp. 185-205.

Zhang, J. and Liu, Z. (2002), "Case-based reasoning and rule-based reasoning for emergency preparedness information system", *Journal-Tongji University*, Vol. 30 No. 7, pp. 890-894.

Further reading

Fan, Y., Luo, Y. and Chen, Q. (2000), "Discussion on quantification method of evaluating vulnerability", *Journal of Catastrophology Indexes of Hazard Bearing Body*, Vol. 15 No. 2, pp. 78-81.

Fogli, D. and Guida, G. (2013), "Knowledge-centred design of decision support systems for emergency management", *Decision Support Systems*, Vol. 55 No. 1, pp. 336-347.

Fonseca, F. and Davis, C. (1999), "Using the internet to access geographic information: an open GIS prototype", in Goodchild, M., Egenhofer, M., Fegeas, R. and Kottman, C. (Eds), *Interoperating Geographic Information Systems*, Kluwer Academic Publishers, Norwell, MA, pp. 313-324.

Fonseca, F., Egenhofer, M., Davis, C. and Câmara, G. (2002), "Semantic granularity in ontology-driven geographic information systems", *AMAI Annals of Mathematics and Artificial Intelligence – Special Issue on Spatial and Temporal Granularity*, Vol. 36 Nos 1-2, pp. 121-151.

Gao, T., Xu, X., Wang, J. and Rui, Li. (2008), "Classification of disaster-affected bodies and vulnerability assessment in low-temperature freezing and snow disaster occurred in South China, 2008: case study of traffic disaster-affected bodies of Chenzhou City in Hunan, China", *Journal of Guizhou Normal University (Natural Sciences)*, Vol. 26 No. 4, pp. 14-21.

Guarino, N. (1998), "Formal ontology and information systems", *Proceedings of the 1st International Conference on Formal Ontology in Information Systems, IOS Press*, pp. 3-15.

He, Q.L., Ghobadian, A. and Gallear, D. (2013), "Knowledge acquisition in supply chain partnerships: the role of power", *International Journal of Production Economics*, Vol. 141 No. 2, pp. 605-618.

Liu, Y. (2013), *The Knowledge Modelling and Effect on Disaster Diffusion of Hazard Bearing Body Vulnerability*, Dalian University of Technology, Dalian.

Shi, P. (1996), "Theory and practice of disaster study", *Journal of Natural Disasters*, Vol. 5 No. 4, pp. 6-17.

Shi, P. (2002), "Theory on disaster science and disaster dynamics", *Journal of Natural Disasters*, Vol. 11 No. 3, pp. 1-9.

Shi, P. (2005), "Theory and practice on disaster system research in a fourth time", *Journal of Natural Disasters*, Vol. 14 No. 6, pp. 1-7.

Zhang, F., Zhong, S., Sun, C., Huang, Q. and Chen, J. (2014), "Research scheme on pre-assessment theory and method for influences of disastrous meteorological events", *International Journal of Advances in Management Science*, Vol. 3 No. 4, pp. 117-122.

Corresponding author
Shaobo Zhong can be contacted at: zhongshaobo@tsinghua.edu.cn

---