Ontologies for Crisis Management: A Review of State of the Art in Ontology Design and Usability

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ABSTRACT

The growing use of a variety of information systems in crisis management both by non-governmental organizations (NGOs) and emergency management agencies makes the challenges of information sharing and interoperability increasingly important. The use of semantic web technologies is a growing area and is a technology stack specifically suited to these challenges. This paper presents a review of ontologies, vocabularies and taxonomies that are useful in crisis management systems. We identify the different subject areas relevant to crisis management based on a review of the literature. The different ontologies and vocabularies available are analysed in terms of their coverage, design and usability. We also consider the use cases for which they were designed and the degree to which they follow a variety of standards. While providing comprehensive ontologies for the crisis domain is not feasible or desirable there is considerable scope to develop ontologies for the subject areas not currently covered and for the purposes of interoperability.

Keywords

Ontologies, crisis management, information interoperability, ontology design and usability, semantic web.

INTRODUCTION

In crisis management, different domain vocabularies are used by different crisis information systems. This presents a challenge to exchanging information efficiently since the semantics of the data can be heterogeneous and not easily assimilated. For example, the word ‘Person’ can have different meanings - a ‘displaced person’, ‘recipient of aid’, or ‘victim’. Semantic interoperability is a key challenge to interoperability (Sheth, 1999). The term “semantic interoperability” refers to the ability of computer systems to communicate data with a unified meaning (Sheth, 1999). One way to tackle this problem is using ontologies to make accessible data that would otherwise be inaccessible (Wache, Vögele, Visser, Stuckenschmidt, Schuster and Heumann, 2001). This is because an ontology can provide a unified explanation of concepts and relationships used by the application field, make them shareable by different users and allow them to be machine process-able.

A variety of application specific ontologies have been developed for crisis information management, which enable interoperability in specific scenarios. The need to develop open standards that make it possible to address the interoperability challenge in crisis management has been recognised as significant (Di Maio, 2008). A prerequisite to meeting this challenge is to have an overview of the currently existing ontologies that have been developed to address these requirements. Hence, the focus of this paper is a review of existing ontologies for crisis management. Specifically, this paper identifies the subject areas covered by the concepts in these ontologies, the types of crisis management systems they address, and how these ontologies were designed and used.

This paper is structured as follows. In the Methodology section, we present the research questions that we are considered in our review. We then describe the data collection and analysis methods used to extract relevant information for our investigation. Next, we present the findings in the Results section, including the identified subject areas involved in crisis management, the ontologies that cover these subject areas, a detailed reflection on the design and usability of the ontologies and the standards that these ontologies conform to. Last, we provide a summary of the findings and the potential impact of our research in the Conclusion section.

METHODOLOGY

Research Questions

From the perspective of information management, crisis management is a complex domain with many pieces of information and corresponding concepts involved before, during and after a crisis. The current literature fails to provide an overall picture of the subject areas involved in crisis management and how the concepts should be represented in crisis information systems. Consequently, we aim to answer the following research questions:

i. What subject areas do the concepts used in crisis management belong to? What are the currently existing ontologies that cover these subject areas?

ii. How are the existing ontologies for crisis management designed and used?

iii. What standards, if any, do the existing ontologies relevant to crisis management conform to?

Data Collection

The collection of data was completed in two stages: collecting papers to identify the subject areas; and, collecting ontologies that cover these subject areas. In order to collect papers for the review, we searched databases and forums relevant to crisis management, information systems and semantic web – including Springer Geographical Information Systems journals, Springer Lecture Notes in Geoinformation and Cartography book series, IOS Press Semantic Web journals, IOS Press AI Communications, Oxford University Press The Computer Journal, IEEE Computer Society Digital Library, ACM Digital Library, ISCRAM (International Conference on Information Systems for Crisis Response and Management) and ESWC (Extended Semantic Web Conference).

Moreover, we derived a set of rules for the inclusion of papers, which included:

– The work should present the design, implementation, analysis or evaluation of an ontology-based crisis information system.

– If two or more papers describe the same system, the latest or more comprehensive one was included.

– If the paper does not present an ontology-based crisis information system, it should describe information interoperability requirements and challenges for crisis management.

Nineteen papers were finally selected to include in our review (for the list of papers see http://www.disaster20.eu/D2_iscram2013.htm). From each paper, the keywords highlighting the concepts presented in that paper was added to a list of subject areas. The number of papers in which a keyword appeared was counted for every keyword on the list. In total, eleven subject areas were identified based on the analysis of the keywords. Details of the subject areas will be described in the Results section.

Beyond the selected papers from the first phase of data collection, we also searched the Web to identify relevant ontologies that did not appear in academic papers. The search engines and online ontology libraries we used include Google, Swoogle[1], Watson[2], and DAML Ontology Library[3].

Furthermore, we formulated a set of rules for ontology inclusion, as follows.

– Ontologies designed originally for crisis management and ontologies designed for other domains that can provide appropriate concepts relevant to the crisis subject areas are included.

– Different approaches to ontologies including formal ontologies, taxonomies, schemas and data models are considered.

– Incomplete ontologies are excluded from our review (e.g. ontologies that are currently under development).

The number of relevant ontologies collected was 26. The analysis methods used for investigating the collected ontologies are presented in the following subsection.

[1] http://swoogle.umbc.edu

[2] http://watson.kmi.open.ac.uk/WatsonWUI/

[3] http://www.daml.org/ontologies/

Data Analysis

The following sub-questions were pursued for a deeper analysis of the data collected. The roman numerals I, II, III before the en dash indicates the research questions pursued and the numbers after the en dash refer to the sub-questions posed for a research question.

- QI-1: What subject areas describe the range of concepts involved in crisis and disaster management?
- QI-2: What ontologies exist that cover each subject area?
- QI-3: Does an individual ontology include concepts in one subject area or in multiple subject areas?
- QI-4: Is the ontology represented formally? If yes, what language is used to describe the ontology?
- QI-5: Is the ontology publicly accessible e.g. downloadable from a website?
- QII-1: What is the purpose of the ontology e.g. the type of crisis management system it is aimed for?
- QII-2: How many concepts or terms are defined in the ontology?
- QII-3: What categories of concepts are defined in the ontology e.g. classes, object properties and/or data properties?
- QII-4: What is the approach or principle used to design the ontology?
- QII-5: Is there a use case that demonstrates the functionalities of the ontology?
- QIII-1: Does the ontology utilise any standard data models, formats, schemas and/or languages e.g. RDF/OWL, OGC standards?

RESULTS

The findings for each research question are described in separate sections. The sub-questions presented in the data analysis section are linked to relevant findings with the question codes in parentheses.

Research Question I

A total of 11 subject areas were represented in contemporary crisis information systems. The types of crisis information system reviewed include critical infrastructures (20%), resource management (13%), decision support (13.3%), situation awareness (13.3%), response coordination (6.7%), command and control (6.7%) and other types (26.7%) such as humanitarian response and relief. A brief description of the identified subject areas is presented in the following list (QI-1).

- Resources: an area referring to the material and human resources that are available or potentially available for assignment to incident operations (e.g. vehicles, warehouses, tents).
- Processes: procedures and tasks that emergency management personnel need to perform in order to prepare for and respond to a crisis event (e.g. search and rescue, traffic control, evacuation).
- People: emergency management personnel which include first responders, policy makers and disaster relief operators.
- Organisations: a variety of working groups that are in charge of crisis planning and response. It includes but is not limited to governments, military, charities and non-governmental organisations.
- Damage: an area referring to the effects of a crisis event on human, physical, natural and economic entities. Examples include injuries, missing people, missing pets, gutted buildings and burned forest.
- Disasters: a subject area concerning the classification of disastrous events or crises. Example categories include natural disasters and technological disasters.
- Infrastructure: a subject area referring to the critical physical and organisational infrastructure upon which humans heavily depend on in their normal daily life.
- Geography: a subject area providing geospatial information about disasters such as the position of a place where an incident occurs, the geo-location of displaced people and where shelters are located.
- Hydrology: information about water including the type of a water body, its location, current, and how it moves across the landscape.
- Meteorology: information about weather and climate including humidity, precipitation, pressure, visibility, wind, storm and lightning, and average changes of weather during a long period of time.
- Topography: a subject area dealing with the surface shape and features of the Earth. It provides information on the terrain, ecological regime, division, and built-up area of the location where a crisis

happens.

The subject areas identified show two groups of concepts involved in crisis information systems: common concepts (people, organisations, resources, disasters, geography, processes, infrastructure, damage) and unusual concepts (topography, hydrology and meteorology). Common concepts were more frequent keywords in the selected papers while unusual concepts occurred less frequently as keywords.

A summary of the number of the ontologies identified, their names, representation languages, accessibility and documentation for each subject area is presented in Table 1 (QI-2, QI-4, QI-5). Since some ontologies represent concepts in multiple subject areas, an ontology is assigned to the subject area where the main purpose of the ontology lies. In Table 1, hyperlinks are available for the online specifications and query portals.

Subject Area	Number of Ontologies Identified	Ontology Name	Representation Language	Downloadable	Documentation
Resources	3	SOKNOS	OWL-DL	No	Minimal (academic nature)
		MOAC	RDF	Yes	*Online specification*
		SIADEX	Not known	No	Minimal (academic nature)
Processes	2	ISyCri	OWL-DL	No	Minimal (private wiki and in French)
		WB-OS	XML	Available upon request	Academic nature
People	2	FOAF	RDF	Yes	*Online specification*
		BIO	RDF	Yes	*Online specification*
Organisations	3	ERO²M	N/A	No	Academic nature
		IntelLEO	RDF	Yes	*Online specification*
		Organisation Ontology	RDF	Yes	*Online specification*
Damage	1	HXL	RDF	Yes	*Online specification*
Disasters	4	EM-DAT	N/A	*Online query*	*Classification of disasters available*
		UNEP-DTIE	N/A	*Online query*	*Online documentation*
		Canadian Disaster Database	N/A	*Online query*	*Classification of disasters available*
		Australian Government Attorney-General's Department Disasters Database	N/A	*Online query*	*Online documentation*
Infrastructure	3	PSCAD	N/A	No	Minimal (academic nature)
		EPANET	N/A	No	Minimal (academic nature)
		OTN	OWL	Yes	*Specification available*
Geography	1	GeoNames	RDF	Yes	*Online documentation*
Hydrology	1	Ordnance Survey Hydrology Ontology	OWL	Yes	*Online documentation*
Meteorology	1	NNEW weather ontology	OWL	Yes	*Online documentation*
Topography	4	USGS CEGIS	OWL	Yes	Not available
		Ordnance Survey Buildings and Places Ontology	OWL	Yes	*Online documentation*

		E-response Building Pathology Ontology	OWL	Yes	Not available
		E-response Building Internal Layout Ontology	OWL	Yes	Not available
Other	1	AktiveSA (multi-domain)	OWL	Yes	Not available

Table 1. Subject Areas of Information Entities in Crisis Management and Ontologies that Represent the Subject Areas in Terms of Representation Language, Accessibility and Documentation

From Table 1, among the ontologies designed originally for crisis management, very few are formally represented and publicly accessible. Crisis oriented ontologies such as SOKNOS (Babitski, Probst, Hoffmann and Oberle, 2009), ISyCri (Benaben, Hanachi, Lauras, Couget and Chapurlat, 2008) and WB-OS (Chen-Huei, Zahedi and Huimin, 2011) are formally represented but are not publicly available. Moreover, no formal ontologies are specifically intended for representing the emergency and disaster domain. The existing ontologies that represent the disaster subject area are mainly in the form of database schemas, which are not publicly available.

Most of the ontologies identified (20 out of 26) describe concepts in a single subject area. However, a few ontologies represent multiple subject areas (QI-3). These include SOKNOS (three areas: resources, damage and disasters), MOAC (four areas: resources, processes, damage and disasters), SIADEX (de la Asunción, Castillo, Fdez-Olivares, García-Pérez, González and Palao, 2005) (three areas: resources, processes and geography), ISyCri (three areas: processes, damages and disasters), HXL (four areas: damage, geography, organisation and disasters), and AktiveSA (Smart, Russell, Shadbolt, Schraefel and Carr, 2007) (seven areas: geography, infrastructure (transportation), meteorology, processes, resources, organisations and people).

Research Question II

This subsection presents the research findings regarding purpose, design and usability of the currently existing ontologies relevant to crisis management. The question QII-1 concerns the types of crisis management systems that the ontologies are aimed for and the requirements for information representation in the systems. A brief explanation of the findings for QII-1 is presented in Table 2.

Representative Crisis Ontologies	Types of Crisis Management Systems aimed for	Requirements of Information Representation
SOKNOS	Information integration for resource planning	Categorisation of damages and resources, deploy regulations defining the relations between them
SIADEX	Planning under uncertainty for decision support	Taxonomy of resources, legal information on the use of resources, operational targets and tasks for specific crisis scenarios, representation of uncertainty (temporal, resource and location)
ISyCri	Crisis response coordination	Categories of entities affected by crises, the treatment system, the crisis description
MOAC, HXL	Humanitarian disaster response and relief	Classification of damages, crises, response activities and resources; geo location about displaced persons
WB-OS	Web sites for disaster management	Features, components and information used to create disaster management web sites

Table 2. Representative Crisis Ontologies, Intended Types of Crisis Management Systems and Requirements for Information Representation in the Systems

Many of the ontologies identified (as listed in Table 1) are not originally designed for crisis management systems – so are not presented in Table 2. Although the reasons for building these ontologies depend on thei specific application domains, they hold interest for crisis management since they provide relevant representations of the concepts required by crisis management activities. For example, GeoNames provides geographical terms such as country code and postal code that can be used to encode geospatial information about the places where incidents occur.

Next, a summary of the numbers and categories of concepts defined in the ontologies identified is provided in Table 3 (QII-2, QII-3).

Ontology	**Classes**	**Object Properties**	**Data Properties**	**Instances**	**Total Entities**
MOAC	92	21	21	0	134
SOKNOS	*	*	*	*	*
SIADEX	> 130	*	*	> 2000	> 2130
ISyCri	*	*	*	*	*
WB-OS	-	-	-	-	2094 web elements
FOAF	18	41	27	0	86
BIO	53	35	3	0	91
ERO^{2}M	11	6	0	> 40	> 57
IntelLEO	21	35	4	17	134
Organisation Ontology	10	21	3	0	34
AKTiveSA	2256	166	19	359	2800
HXL	49	37	24	33	143
EM-DAT	-	-	-	-	-
UNEP-DTIE	-	-	-	-	-
Canadian Disaster Database (disaster classification)	-	-	-	-	-
Australian AG Disaster Database (disaster classification)	-	-	-	-	-
PSCAD	*	*	*	*	*
EPANET	*	*	*	*	*
OTN	179	35	73	0	287
GeoNames	12	19	15	690	736
Ordnance Survey Hydrology Ontology	193	43	0	14	250
NNEW Weather Ontology	360	146	8	0	514
USGS CEGIS	759	94	2	0	855
Ordnance Survey Buildings and Places Ontology	708	33	0	9	750
E-response Building Pathology Ontology	82	3	7	17	109
E-response Building Internal Layout Ontology	18	0	0	0	18

Table 3. Number of Classes, Properties and Instances Defined for Ontologies Relevant to Crisis Management (Total Number of Ontologies Identified: 26)

*: The number cannot be counted since the ontology is not publicly accessible.

-: It is not appropriate to count the number because the vocabularies are not formally specified or it is database oriented which does not provide a formal representation of disasters and their properties.

From Table 3, 17 out of 26 ontologies consist of concepts in four categories that a formal ontology typically contains: classes, object properties, data properties, and instances. In addition, 9 out of 16 could not be counted (not public or not formally specified). The majority of the countable ontologies (65%) are lightweight (containing on average 119 concepts). Only a third of the countable ontologies are relatively large (containing over 1200 concepts on average).

The following descriptions emphasise the approaches or principles used to design the ontologies that represent each subject area (QII-4).

For the resource ontologies identified, two different approaches are applied to represent the resource concepts. The first approach is called the “Emergency Cluster Approach” (defined by Inter Agency Standing Committee - IASC), which describes material resources in clusters and is not devoted to describe specific resource types. The MOAC ontology falls into this category since it conceptualises humanitarian needs and aids instead of providing a detailed classification of resources. The second approach focuses on defining a hierarchical structure of material resources and human resources. The SOKNOS and the SIADEX resource ontologies belong to this group. The purpose of defining a hierarchical structure containing specific resource types is to provide adequate knowledge required by emergency planning and control processes (e.g. planning and scheduling for forest fire fighting).

The existing process ontologies describe process related concepts from two perspectives: crisis response and governance regarding disaster management. The ISyCri ontology is an example of the first category, which conceptualises a response system dealing with crisis situations. Concepts regarding the response system involve actors, their resources, the services they provide and their procedures. The second perspective focuses on building ontologies for describing the structure and elements of government web sites for disaster management. The purpose of building the ontologies is to provide a metric for measuring the adequacy of the contents of relevant government web sites in terms of preparation, response and recovery of disasters and good lessons learned from previous disasters. The WB-OS ontology provides a comprehensive view of the web elements that a government web site should contain regarding disaster management.

In terms of ontologies describing people, two aspects of information about people are captured: characteristics and the biography of people. The characteristics of people represented in these ontologies include names, images, the projects a person is currently working on and has previously worked on, homepages, other persons that the person knows about, and the homepage of an organisation they work for. FOAF is such an ontology that defines terms representing characteristics of people. The biography related information about a person consists of properties of a person (e.g. father, mother, child, and biography), types of event (e.g. employment, graduation, and promotion) and properties that relate an event to an agent (e.g. employer and organisation). BIO is a formal ontology that describes these biographical vocabularies.

Regarding the existing ontologies for describing organisations, three aspects of concepts are focused on: organisation structure, organisation policy and organisation types. The Organisation Ontology emphasises defining terms to represent organisational structure including composition units, roles, reporting structure, location and history (e.g. merger, renaming and repurposing). The IntelLEO Organisation ontology encompasses concepts that represent organisation policy for competence requirements of positions, in addition to describing the structure of an organisation. The AKTiveSA Organisation ontology provides an ontological characterisation of five types organisations: military organisations, research and monitoring organisations, religious organisations and sects, terrorist organisations and humanitarian organisations. ERO^{2}M (Wang, Zhang, Dong, Gao, Du and Lai, 2009) was designed particularly for describing emergency response organisation and covers the above mentioned three aspects of concepts, which are further categorised into goal, department, position, personnel, role, skill, specialised organisation and temporary organisation. The design of ERO^{2}M aligns its conceptual model to the upper level ontology “SUMO” (Suggested Upper Merged Ontology) (Niles and Pease, 2001). The advantage of conforming to a upper level ontology lies in the ability to aligning the model to a set of common and cross-domain notions and thus can reduce the heterogeneity in domain specific ontologies.

For the ontologies capturing types of damage, two approaches are used. The first approach is providing a taxonomy of damage based on classification criteria, which include the type of object damaged, the aspect damaged (e.g. its functionality), the environment in which the damage occurs and its causes. Examples include the SOKNOS Damage ontology and the ISyCri Damage ontology. The criterion “the type of object damaged” is used primarily in SOKNOS since this criterion is more prominent in common perception. The other criteria were inferior to the primary classification criterion. The second approach is focusing on defining concepts for expressing more specific types of damage (e.g. damages to humans). Examples include HXL and MOAC. HXL defines a set of vocabularies to describe populations affected by an emergency—deaths, injured, missing, displaced and non-displaced population, refugees and asylum seekers. MOAC incorporates a small section of terms representing affected population—deaths, missing persons, people trapped and highly vulnerable people.

In terms of the disaster area, most of the vocabularies identified—either formal or informal— emphasise the classification of disasters. Disaster databases including EM-DAT and UNEP-DTIE categorise disasters into two typical groups: natural disasters and technological disasters. The natural disasters are caused by natural factors such as biological, meteorological, hydrological and geological. The technological disasters are caused by technological reasons that could affect life, society and the environment such as a transport accident, infrastructure failure, hazardous chemicals and explosions. In addition to the two typical groups of disasters, the Canadian Disaster Database describes a new group of disasters—the conflict disasters—for categorising disasters caused by humans due to conflicts and disagreements in nature such as arson, civil incident, hijacking and terrorism. However, the classifications of disasters provided by the disaster databases are informal (i.e. text-based description). The formal ontologies relevant to disasters are holistic ontologies that contain a small section defining terms for disaster related concepts—the types and properties of disasters. MOAC contains a very small section defining terms for six types of disasters. ISyCri provides a sub module defining terms for representing the properties of a crisis including trigger, effect, and factors that could affect the type and gravity of a crisis.

Regarding the critical infrastructure area, existing ontologies were created from two perspectives. The first is representing the domain simulators (e.g. simulators for observing and analysing the behaviours of power system networks and water distribution), and the interdependencies between them. The purpose of representing the interdependencies is to enable the domain simulators to be integrated in a federation and thus exchange information in a semantic manner. Examples of the first type include PSCAD for conceptualising power system simulators (Grolinger, Capretz, Shypanski and Gill, 2011) and EPANET for representing water distribution simulators (Grolinger et al., 2011). For PSCAD and EPANET, classes were defined to represent the component categories of the corresponding simulators. For example, the top level of component categories defined in PSCAD includes sources (e.g. controllable current and voltage sources), I/O devices (e.g. transformers), machines, transmission lines, meters, breakers and faults. Moreover, an upper ontology is used to represent a generic view of the individual ontologies with fundamental component categories. Concepts of individual domain ontologies (i.e. PSCAD and EPANET) are aligned to this upper ontology. The second perspective is conceptualising geographic information in infrastructure systems (e.g. transport systems). OTN is a formal description of the Geographic Data Files (GDF) ontology (GDF is an ISO standard for specifying how to store geographic information for intelligent transport systems). OTN consists of five groups of classes: feature (all GDF features as OTN classes), geometric (the geometric forms of features), composite_attributes (i.e. a group of owl:ObjectProperty properties), relationship (non-geometric relationships between features) and transfer_point (i.e. classes which describe how to get from one object to another).

Regarding the geography area, the ontologies identified provide formal conceptualisation of toponyms and the relationships between individual toponyms (both administrative and spatial). GeoNames is the largest among these ontologies, which defines a web of toponyms. The description of a toponym is represented as a “Feature” class and a set of properties—name, feature code (a length of 2-5 alphabets and/or digits), country code, population, postal code, longitude and latitude— is defined for the toponym. Moreover, two “Feature” classes can be linked to each other using object properties that represent relationships between two toponyms, including children (e.g. administrative subdivisions for a country), neighbours (neighbouring countries) and nearby. The geographical vocabularies are useful for encoding geospatial data in crisis information systems. For example, the longitude and latitude vocabularies can be used to describe the position of a place where an incident happens. HXL, as well, provides a small section of vocabularies to describe geo location information about shelters, displaced people and administrative units (e.g. country and populated place).

The hydrology area aims to describe all information about water. It includes the types of water (e.g. river, lake, stream, waterfall), where it is, whether it has a current or not, and how it moves across the landscape. The UK Ordnance Survey Hydrology Ontology represents topographic features about various water bodies. For example, a waterfall is defined as a topographic object, which is a part of a river or stream and is located at a cliff, a slope or an escarpment. The Ordnance Survey Hydrology Ontology (current public version) does not provide vocabularies for representing hydrometric data—where the hydrometric stations are, what type of water body a hydrometric station is monitoring, what administrative region the station belongs to, and the real time water level that the hydrometric station has measured. Vocabularies for describing hydrometric data are important to disaster preparedness and response since they can provide essential information on flooding conditions.

The meteorology area deals with information about weather and climate. The weather domain describes information about a short period (from day to day or hour to hour) of temperature, precipitation and wind activity while climate refers to the average weather over a long period of time. The NNEW Weather Ontology provides a formal conceptual model of the weather domain. The NNEW ontology adopts a modular structure that consists of 8 modules: humidity, lightning, measurement, precipitation, pressure, storm, visibility and wind. Each of the modules corresponds to an individual subdomain, such as humidity or pressure. They are self-contained and are combined to make up the complete NNEW ontology. For example, the NNEW precipitation module defined terms for describing precipitation from a meteorological perspective. It includes the types of precipitation (e.g. drizzle, rain, sleet, snow, and hail), the measurement of precipitation (e.g. accumulation, depth, frequency, and temperature), and the operations of the measurements (e.g. maximum, minimum, mean, standard deviation). No climate ontologies were identified for our review. This is probably because for the emergency response community, weather-related information is relatively more important since the weather has a more direct and immediate impact.

For the ontologies capturing topographical concepts, a reverse-engineering approach (i.e. designing an ontology from data already existing) is mainly used to specify the concepts and semantic relationships between them. This approach refers to the geospatial databases of a national map for constructing the topography ontology. Examples include the USGS CEGIS ontology (Varanka, 2009) and the UK Ordnance Survey Buildings and

Places ontology. The USGS CEGIS ontology specifies six groups of topographic features consisting of events, divisions, built-up areas, ecological regimes, surface water and terrain. These concepts are critical to semantic technology enhanced GIS applications including data integration and retrieval. The purpose of the Ordnance Survey Buildings and Places ontology is to describe the building feature and place classes surveyed by Ordnance Survey (OS). The basic concepts described in the Ordnance Survey Buildings and Places ontology encompass the types of buildings or areas (e.g. farm land, rural area and historic interest), landform (coast, hill, mountainous area and moorland), the purposes of the places (e.g. industrial processing, education, trading, research and housing), people and animals living in the places. Beyond the reverse-engineering approach, ontologies including the E-response Building Pathology and Internal Layout ontologies adopt a scenario-based approach to specify the topographical concepts and relations. The E-response ontology conceptualises the building categories, material, defects and internal structures that are associated with certain hazardous scenarios such as fires, explosions and terrorist attacks that may happen in buildings.

Beyond analysing the design of the ontologies, we searched for use cases of these ontologies. We selected typical uses cases identified and present them in Table 4 (QII-5).

Ontology Name	Use Case	Role of the Ontology
MOAC	crowdsourcing linked open data for humanitarian information management (Ortmann et al, 2011)	It provides a shared vocabulary for incident reporting as linked open data.
NNEW weather ontology	4-D Wx Data Cube – semantic search	It enables the 4-D Wx Data Cub to “translate” between terms to return all semantically similar data and discover resources without exact keyword match via ontology alignments.
FOAF	MOAC	The FOAF vocabulary (foaf:agent) is used in the MOAC ontology to define the class “ShelterAgency” (a humanitarian partner involved in shelter related humanitarian response).
SIADEX	planning system (de la Asunción et al., 2005)	It serves as a knowledge base for providing knowledge required by the planning process.
ISyCri	reasoning about the treatment processes (Benaben et al., 2008)	Can be injected into Protégé for reasoning. Through using Semantic Web Rule Language (SWRL), emergent process elements (e.g. potential actors, preventive services, curative services) are deducted from the reasoning procedure.

Table 4. Use Cases of the Ontologies for Crisis Management and the Roles of the Ontologies

Research Question III

For the third research question, we examined the standards that the ontologies for crisis management conform to for the conceptualisation process (QIII-1). Six ontologies are identified to conform to certain standards, which can be divided into four categories: fundamental ontologies (i.e. models of common and cross-domain concepts), de facto standards, open standards and standards at different levels (e.g. European or national level). A brief description of the analysis results is presented below (QIII-1).

- SOKNOS: follows the principles of DOLCE foundational ontology (Babitski et al., 2009). For example, a class “Device” is defined in SOKNOS which specialises the concept “dolce:Non-Agentive Physical Object” defined in SOKNOS.
- MOAC: conforms to de facto standards developed by Inter Agency Standing Committee (IASC), Emergency Shelter Cluster in Haiti, UNOCHA 3W Who What Where Contact Database and the Ushahidi Haiti Project.
- ERO^{2}M: aligns to the fundamental ontology “SUMO” (Niles and Pease, 2001).
- HXL: links to the OGC GeoSPARQL standard for defining geo location vocabularies.
- OTN: provides a formal description of the Geographic Data Files (GDF) standard, which is an ISO standard for specifying how to store geographic information for intelligent transport systems.
- USGS CEGIS: complied with the Digital Line Graph (DLG) feature list derived from field-surveyed 20th-century maps, the Geographic Names Information System (GNIS), and the Spatial Data Transfer Standard (SDTS).

The above analysis indicates the lack of a common vocabulary or standard for the domain. We perceive this would be one of the hardest goals to meet since it would be a significant challenge to achieve the consensus across all the stakeholders. Moreover, it may not be feasible to share a single domain ontology by various applications as useful domain ontologies are designed for the particular tasks they target. However, it would be feasible to specify terminologies for interoperability gaps that are crucial and have not been addressed yet.

CONCLUSION

In this paper we conducted a thorough review of the ontologies for crisis management field. As a result of the review, we identified a set of critical subject areas that cover the information concepts dealt with in crisis management and the currently existing ontologies that represent these subject areas. All of the identified 11 subject areas are covered by existing ontologies and 65% of the existing ontologies are semantically interoperable. This review provides an overall picture of the subject areas and how they are represented and used in crisis management systems. The findings could provide a basis for identifying the missing terminologies or constructing shared vocabularies for information interoperability. One direction for future work would be identifying the key interoperability gaps in crisis response and management from the results of this review and create formal ontologies that can cover these interoperability gaps.

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