Using Ontologies for Decision Support in Resource Messaging

Jim Steel
NICTA

Renato Iannella
NICTA
renato@nicta.com.au

Ho-Pun Lam
University of Queensland/NICTA
brian.lam@nicta.com.au

ABSTRACT

Emergency management is by its nature, and in some jurisdictions by its definition, an activity that requires a concerted effort by a number of governmental and non-governmental agencies. There is a growing appreciation that collaboration between these parties is best served through the use of interoperable standards for message formats for purposes such as alerting and resource exchange. However, it is also important to realize that, although much advantage can be drawn from standardizing certain aspects of communication, such as the structure of messages, different agencies will use different vocabularies. In this paper we discuss how ontologies can be used with standard messaging formats for resource messaging to enable intelligent decision support mechanisms in the presence of differing vocabularies across organizational boundaries. We also present a survey of the opportunities for using ontologies in emergency management, and the issues that must be addressed.

Keywords

Ontologies, ontology matching, decision support, resource management, emergency management.

INTRODUCTION

The management of emergencies is an endeavour that is characterised by involvement from a multitude of stakeholders, including numerous government agencies, military groups, non-government and charitable organisations, private enterprise and community groups. Some jurisdictions, such as the United States, have attempted to integrate government response under a single emergency response agency, although this can help to manage the logistics of interagency communication, the problem remains, particularly for non-governmental participants.

Of the four commonly identified phases of emergency management – prevention/mitigation, preparation, response and recovery – response poses the clearest immediate need for efficient communication between agencies. However, each phase offers opportunities for improved communications, and indeed, the languages used and the problems faced have significant commonalities across all phases.

The proliferation of participants poses challenges when trying to build information technology solutions to support the management of operations. Without agreement on how stakeholders' information technology solutions can intercommunicate, the use of IT threatens to complicate rather than simplify the processes.

In this paper, we first present the research challenges and a brief overview of related work on resource messaging. This is followed by an example scenario to illustrate the problem of resource messaging during a crisis, and the opportunities for decision support mechanisms. After this, a brief introduction is given to ontologies and ontology mapping technologies, to illustrate how they can help address the problems faced in resource messaging, before the final conclusion.

RESEARCH CHALLENGE

The general consensus in IT is that the co-operation of disparate systems is best addressed through the use of standards, agreed-upon interfaces and protocols of communication that, when adhered to, should guarantee successful interaction with other systems. In the field of emergency management, this is exemplified by recent efforts in organisations such as OASIS, with its Emergency Management Technical Committee (EMTC) introducing standardised message formats for alerts (OASIS, 2005), message distribution (OASIS, 2006) resource messaging (OASIS, 2007a), and hospital bed availability (OASIS, 2007b).

However, these standards can only go so far. Although encouraging stakeholders to use standardised structures can make and has made great strides in garnering agreement on the structures of information being exchanged, the values for data that are being exchanged, the vocabularies being used by the different agencies, present a much greater challenge. There are numerous reasons that different stakeholders use different vocabularies. Different spoken languages, different universes of discourse, different concerns, can each lead to differing terminologies that make it very difficult for stakeholders to exchange information efficiently.

RESOURCE MESSAGING

The particular interoperable standard of interest to this paper is the Emergency Data eXchange Language Resource Messaging (EDXL-RM) standard defined by the OASIS consortium's Emergency Management Technical Committee. The EDXL-RM specification defines an XML schema (more precisely a number of XML schemas) for the exchange of messages related to the management of resources during an emergency, including provision, acquisition, deployment, and return.

In a detailed sense, an EDXL-RM message may be one of 16 different message types, each of which represent a profiled subset of the full message format. So, for example, a RequestResource message may include information related to the type of resource required, about arrangements for its delivery and return, but not about the ownership of the resource (since that may only be specified by the resource supplier).

Although EDXL-RM has not yet reached full OASIS standardisation, it is beginning to be implemented in tools. Figure 1 shows a screenshot of a message construction screen in the CAIRNS (Cooperative Alert Information and Resource Notification System (Iannella et. al., 2007)) emergency messaging demonstrator.

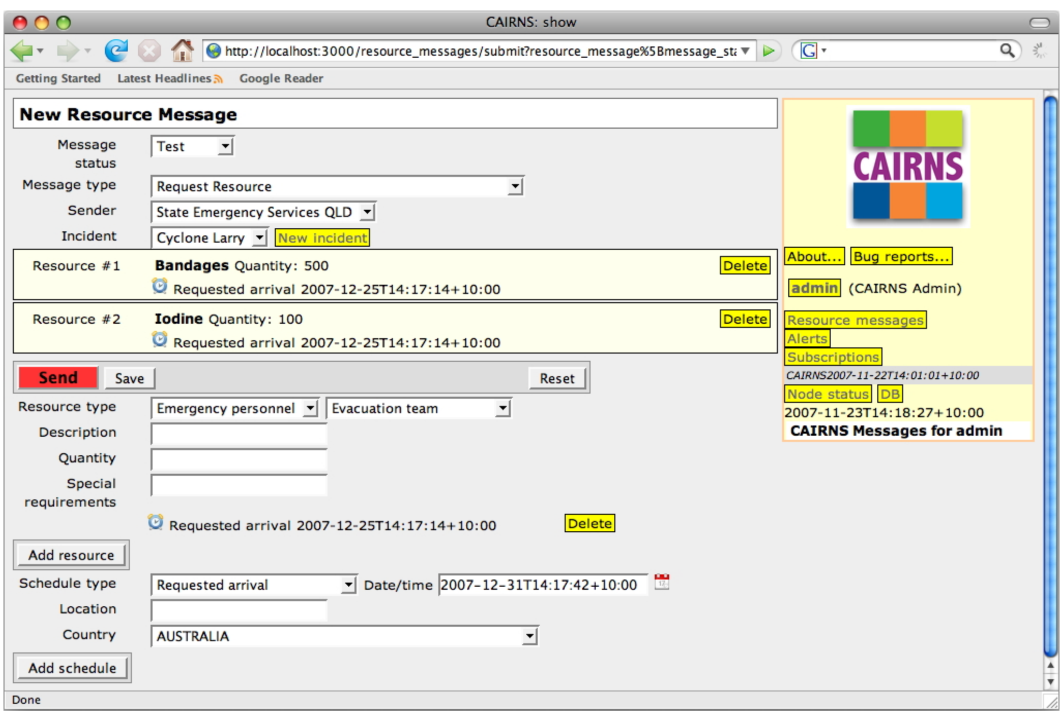

Figure 1 CAIRNS Demonstrator – Resource Messaging Interface

The reference model for EDXL-RM includes structures that allow resource suppliers and consumers to talk about the delivery and return in terms of locations, dates and times in a standardised way. There are also constructs for representing organisational elements, such as specifying the parties that own resources or that will be responsible for resources during their deployment, as well as the addressing of messages within an organisation[1]. Users may also reference the funding arrangements under which the resource exchange is taking place.

There is also some limited capability for remembering the flow of messages, e.g. whether a message was sent in response to another message. However, the specification generally avoids proscribing a protocol for communication in terms of which messages may be sent in response to which others.

Similarly, the specification document allows users to specify details of the resource being discussed, in terms of its quantity, description, specific requirements, and type via a reference into some external resource type registry. However, the document does not proscribe a set of canonical resource types, instead leaving this to the agencies sending or receiving the messages. For example, U.S. government agencies under the auspices of the Deparment of Homeland Security may use the NIMS Resource Typing system. (FEMA, 2007)

EXAMPLE SCENARIO

In order to illustrate the problem of resource messaging, and of diverse emergency response organisations communicating using different terminologies, we present an example scenario. Figure 2 shows a series of messages exchanged amongst different agencies during a cyclone. (For the complete details about the message structure and semantics please see (OASIS, 2007a).)

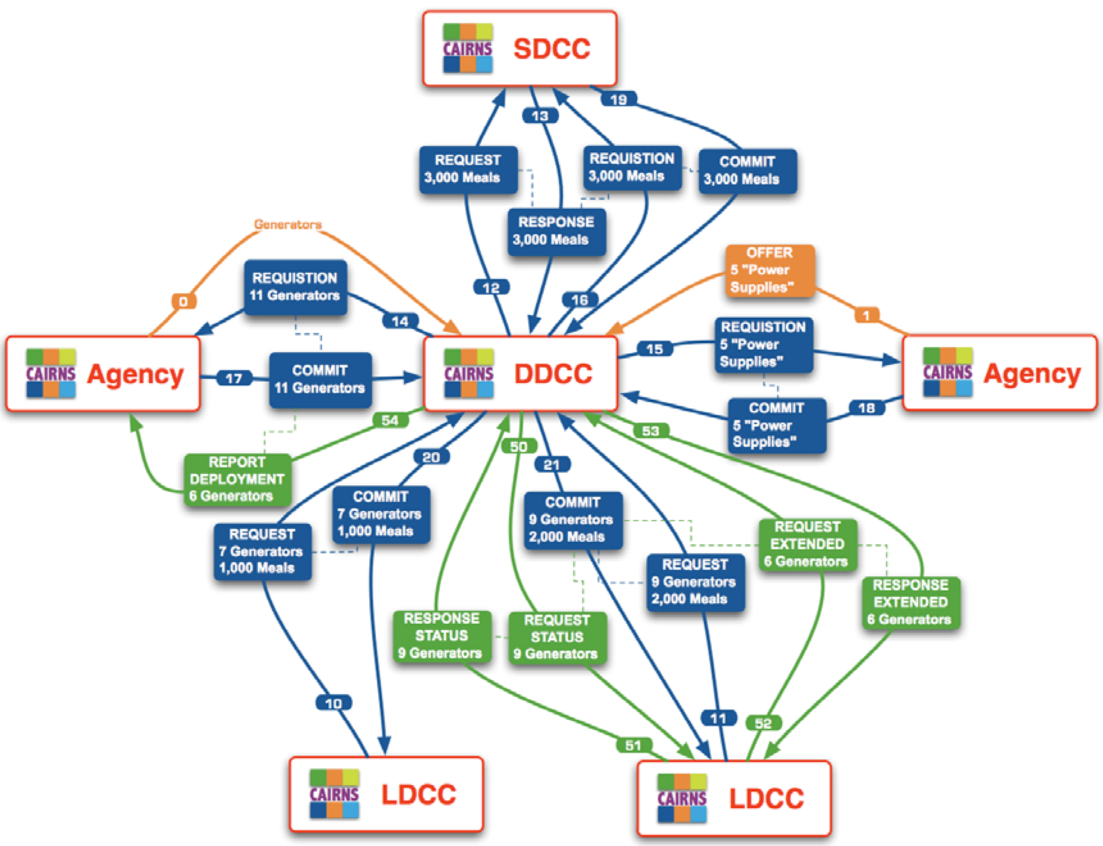

Figure 2 Sample Provisioning Scenario

[1] It is envisioned that RM messages will be exchanged within EDXL Distribution Element (DE) messages. EDXL-DE provides a richer set of constructs for the addressing and routing of emergency messages.

The scenario begins with a resource request from one of the Local Disaster Coordination Centres (LDCC) for 7 Generators and 1000 Packaged Meals and with information about desired times and addresses for delivery, sent to the District Disaster Coordination Centre (DDCC) for the North Queensland District (message 10).

Upon receiving the request, the resource manager at the DDCC notices that a similar request has been received from another LDCC for 9 Generators and 2000 Packaged Meals (message 11). Also, the DDCC have previously received offers from a state government Agency for 5 Power Supplies (message 1). They also note that, in a previous emergency, they received 11 Generators from another agency.

After analysing the situation, and not being able to meet the request from local and district resources, the DDCC sends a request to the State Disaster Coordination Centre (SDCC) for 3000 Packaged Meals, with delivery details corresponding to those received from the local centres. The SDCC responds to negotiate for later delivery of the meals. Requisitions are then sent by the DDCC to the SDCC for the meals under the new delivery arrangements, and to the agencies with available generators and power supplies, with arrangements for delivery (messages 14-16). Each of these suppliers then reply to commit the resources (messages 17-19).

Once the resources have been deployed, there is then a phase of resource deployment management (messages 50-54). The DDCC sends a message to one of the LDCCs requesting the status of the 9 generators. The LDCC sends a response message that 3 of the generators are being returned, and the other 6 are required for longer, which they formalise with a message requesting an extension. The DDCC then responds to approve the extension request, and also sends a status update message to the agency that originally provided the generators.

Decision Support

There are a number of opportunities in this scenario for providing the emergency response personnel at each node with decision support in order to streamline the processing of requests. These include techniques for engineering an emergency management system to have a better semantic understanding of resource types, as well as using semantic and heuristic knowledge to build mechanisms for suggesting actions to emergency response personnel.

In the first instance, when the DDCC operator is dealing with the request for generators and meals from the LDCC, it would be useful to be able to aggregate open requests to make the acquisition of suitable resources more efficient. This aggregation may also extend beyond resources of the same type, and exploit heuristic similarities between open resource requests. For example, had the separate requests been for two different types of fuel, it would still be useful to be advised that they might both be able to be sourced from a petrochemical company. Afterwards, having aggregated requests for the purposes of meeting supply levels, the individual requests must then be consulted again for the deployment of the resources.

Secondly, the DDCC operator could be assisted in identifying existing sources for resources. The previous case experience of having sourced generators from an agency during previous emergency should be leveraged to identify them as a possible source again. An Agency sent an offer using a different vocabulary to that being used within the DDCC, and it necessary for a decision support system to automatically understand that the resource types are compatible, using a vocabulary bridge.

In each of these cases, it would also be useful to prompt the user as to what actions are typically useful in response to certain situations. Much of this can be based on simple analysis of the available message types. For instance, a RequestResource message might be responded to with a ResponseToRequestResource or CommitResource message.

More can be based on heuristic knowledge of the role of the node in the wider emergency response system. In many cases, these systems are codified; in Australia, the Australian Interagency Incident Management System (AIIMS) is quite clear in specifying the organisational roles that are necessary in a response situation. For example, a DDCC might relay a resource request up to its parent State centre.

Alternatively, the actions taken in previous emergencies might be analysed and used to generate suggested actions, e.g. if previous requests for generators were dealt with by requesting generators from QBuild, then that action might be appropriate again.

USING ONTOLOGIES

Ontologies

In a very general dictionary sense, ontology refers to efforts to represent knowledge by categorising and characterising concepts, and the relationships between them. From a more practical, software, sense, the term is used for the practice of setting down the concepts and relationships used in a domain, which is then used to allow reasoning over the objects in the domain based on these concepts and relationships.

Probably the dominant language used for this purpose is now OWL, the Web Ontology Language (W3C 2004a). OWL was developed, as a extension or successor to the simpler Resource Description Framework (RDF) language (W3C 1999, W3C 2004b), and is seen as a building block in the W3C's vision for the so-called "semantic web". This effort essentially revolves around extending the content available on the existing web to be consumable not only by human users, but also by machine processors through its annotation with metadata. Having done this, these resources then become subject for processing using the various techniques developed over many years by the knowledge representation (KR) and reasoning community, such as intelligent search and information brokering.

Structurally, RDF is a very simple language based on the concept of subject-verb-object triples and encoded in an XML syntax. While a very flexible formalism, this is not a very rich set of constructs, and so RDF has been extended, first by RDF Schema (RDFS), which introduces more KR concepts such as class hierarchies (through the use of subtyping) and some frame-based reasoning concepts such as domain and range restriction. One of the motivations for introducing these formal notions as first-class concepts is that it allows an ontology designer to restrict the expressivity of the language they are using. As the ontology language being used increases in expressivity (for example, through its use of universal or existential quantifiers), it can become more difficult to subject to reasoning tools (in terms of computational completeness and decidability). This tradeoff of expressivity against computability has led to a number of conformance points for OWL logics both within (as OWL Lite, OWL DL, and OWL Full) and without the OWL specification document (through the use of Description Logic expressivity properties).

The real advantage of using OWL and other ontology languages comes through the application of reasoning tools. Tools based on frame-based or description logics are able to apply rules to automate deductive processing based on ontological fact-bases. For example, if the messages exchanged during an emergency are stored using ontology formalisms, then it becomes possible to write reasonably simple rules for finding past messaging scenarios corresponding to certain criteria. Clearly, this link with reasoning tools makes ontologies an attractive choice as a basis for building decision support mechanisms for emergency management, particularly in terms of providing case- and rule-based decision support.

Ontologies in Resource Messaging

Within the context of emergency resource messaging, ontologies could be used in a number of places. There are numerous places in the EDXL specifications where the data-values used for populating a structure have deliberately been left empty, so that national or transnational bodies may populate them with vocabularies and terminologies that make sense for their organisational context. This includes the severities and classifications of emergencies, the organisational structures and roles that are in play, the names of geographical locations, and many others. The one of particular interest in the context of the example presented above is resource types and classification.

In addition to some simple descriptors (such as keywords) that can be used for resource identification, there are a number of other existing sources for ontologies for resource types. These include formal vocabularies, taxonomies, and thesauri used and developed by the emergency management stakeholders.

Emergency Management Australia has a thesaurus of terms for emergency management (EMA 1998), which defines agreed terms for the practices that are employed during emergencies, the parties that are involved, the phenomena that are observed, and at a broad level, the resources that can be employed. The document is simple in structure; figure 3 shows an example of an entry, for Emergency power supplies. The term definitions fit easily into an ontology language. We have a full OWL representation of this thesaurus for integration in the CAIRNS tool.

Emergency power supply

Emergencies	Broader Term
Power supplies	Broader Term
Emergency supplies	Related Term

Figure 3 EMA Thesaurus Entry

NIMS (National Emergency Management System) resource types are another source, used by United States government agencies reporting the Department of Homeland Security. NIMS Resource Typing is substantially smaller than the EMA thesaurus, since it is concerned only with resource types. Also, NIMS Resource Typing uses a very different, much richer structure for representing types of resources, defining them in terms of their constituent parts, their attributes, and often using graduated levels for larger or smaller resource types within a single family. Figure 4 shows an example from NIMS for Generators.

U.S. Department of Homeland Security
Federal Emergency Management Agency

Resource: Generators

Category: Public Works and Engineering (ESF #3)
Kind: Equipment

Minimum Capabilities (Component)	Minimum Capabilities (Metric)	Type I	Type II	Type III	Type IV	Type V
Equipment	KW	**XQ2000** 2000 kW Generator; Sound attenuated; Trailer mounted (semi tractor); Up to 3015 Amps@ 480 Volts, 3 Phase, 60 Hz; Dry weight 89,000 lbs; Fuel tank capacity 1250 Gallons; Dimensions 40' Long x 8' Wide x 13'.5" Tall; Potential application example– Single or multiple units for: Power plants, heavy industrial facility, high-rise buildings; Setup time (cables from generator to main power feed estimated at 5+ hours)	**XQ1500** 1500 kW Generator, Sound attenuated; Trailer mounted (semi tractor); Up to 2260 Amps@ 480 Volts, 3 Phase, 60 Hz; Dry weight 59,000 lbs; Fuel tank capacity 1250 Gallons; Dimensions 40' Long x 8' Wide x 13'.5" Tall; Potential application example– Single or multiple units for: Universities, hospitals, medium to large manufacturing facility; Setup time (cables from generator to main power feed estimated at 5+ hours)	**XQ600** 600 kW Generator; Sound attenuated; Trailer mounted (semi tractor); Up to 2080 Amps@ 208 Volts, 3 Phase, 60 Hz / up to 902 Amps@ 480 Volts 3 Phase, 60 Hz; Dry weight 37,000 lbs; Fuel tank capacity 660 Gallons; Dimensions 40' Long x 8' Wide x 13'.5" Tall; Potential application examples: Retail stores, HVAC system power, multi-story/buildings, light manufacturing, apartment buildings; Setup time (cables from generator to main power feed estimated at 3+ hours)	**XQ400** 400 kW Generator; Sound attenuated; Trailer mounted (pull behind); Multi-voltage distribution panel; Up to 1390 Amps @ 208 Volts, 3 Phase, 60 Hz/up to 602 Amps@ 480 Volts 3 Phase, 60 Hz; Dry weight 16,800 lbs; Fuel tank capacity 470 Gallons; Dimensions 23' Long x 8'.5" Wide x 11' Tall; Potential application example: Large office building, public schools, libraries, and communication equipment. Setup time (cables from generator to main power feed estimated at 2+ hours)	**XQ125** 125 kW Generator; Sound attenuated; Trailer mounted (pull behind); Multi-voltage distribution panel; Up to 433 Amps@ 208 Volts, 3 Phase, 60 Hz / up to 188 Amps @ 480 Volts 3 Phase, 60 Hz; Dry weight 10,610 lbs; Fuel tank capacity 223 Gallons; Dimensions 18'.5" Long x 6'.5" Wide x 9' Tall; Potential application example: Small office building, emergency mobile trailers & operations, restaurants. Setup time (cables from generator to main power feed estimated at 1 hour)

Comments:

2500-gallon external fuel tanks available. Fuel consumption is estimated at 7% of the kW usage (example: fuel consumption on a 100 kW Generator operating at full load is approximately 7 gallons per hour). Technicians are available for hookup and monitoring of equipment. 4/0 Quick connect (Cam-Lock) cable is available for tie-in to power feed, rated at 400 Amps each cable. Fuel supply, and/or fuel vendors available. Power distribution equipment available. Transformers & Load Banks are available.

XQ2000 XQ1500 XQ600-400 XQ125

Figure 4 NIMS Resource Typing entry

Other organisations will use different ontologies. Non-government organisations that work closely with the United Nations agencies may use specifications emanating from that body, such as the something like UN Standard Product and Service Code (UNSPSC).

The first step in using these ontologies in a structured way for decision support is in formalising their representation. We have chosen to do this in OWL using the Protégé tool (and thus using the OWL DL subset). However, because of the way the terminologies are defined, even when expressed in a common ontology language (OWL), ostensibly similar terms can still be quite different. For example, the terms shown in Figure 3 and 4 represent similar concepts, but are expressed using very different idioms, and at very different levels of abstraction. These differences are significant when attempting to bridge the terminologies.

Ontology Mapping

Having a single domain ontology shared by various applications may not be feasible in most cases. This is due to the fact that domain ontologies do rely on the particular task at hand and on the organization that develops them. This distributed nature of ontology development has led to a large number of ontologies covering the *same* or *overlapping* domains. Various organizations develop their own ontologies without fully understanding each other. Hence, ontological heterogeneity becomes the first problem that needs to be solved while designing an ontology-based system. As such, ontology engineers face the problem of integrating different ontologies, either to support communication amongst the existing and new domains, or to enable interoperability across heterogeneous systems (Ding and Foo, 2002).

Ontology mapping is the process of identifying the correspondences (mappings) between the concepts of two ontologies. It aims to solve the syntactic and semantic heterogeneity problem and can be done (semi-)automatically (Maedche et. al., 2002; Kalfoglou and Schorlemmer, 2003; Doan et. al., 2003; Li, 2004; Tang et. al., 2006) or manually with the help of ontology experts.

In general, an ontology mapping process includes several subtasks: *map discovery*, *map representation* and *map execution* (Omelayenko, 2002).

Map discovery is the first and most important step in the ontology mapping process. It aims to detect the mismatches and similarity measures between different ontologies entities. Figure 5 below shows a possible alignment of ontologies representing the two resource typing ontologies discussed in the previous section.

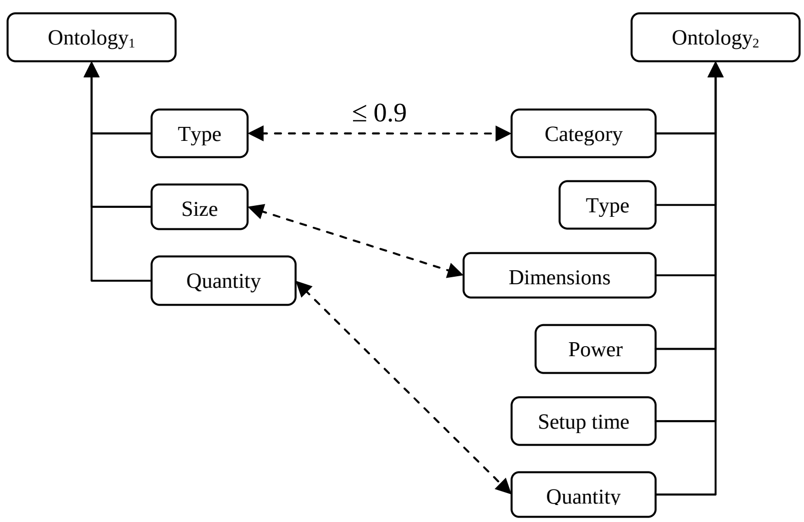

Figure 5 Alignment between ontologies of the two resources typing systems (correspondence are expressed by dashed arrows; by default their relation is "=" and their confidence value is 1.0, otherwise, this is mentioned near the arrow)

Over the years, various techniques have been developed to measure the similarities of entities at different levels of abstraction (Euzenat and Shvaiko, 2007). In our case, techniques such as String-based approaches, Language-based approaches or Linguistic resources can be used to measure the similarities between different entities.

Map representation concerns all activities of representing the identified equivalent relations of ontologies in a formal way. Yang and Steele (2007) have classified different representation approaches into two categories: (i) 1-to-1 mapping representation, and (ii) ontology-based mapping representation. 1-to-1 mapping representation is an instance-level representation approach that links the concepts inside the two ontologies together directly. Mapping can be done efficiently using simple rules but is not suitable for ontologies with information granularities or complex ontology mappings. On the other hand, ontology-based mapping representation uses ontology to represent the relations between the two ontologies. This second approach is more accurate and effective, especially for complex ontology mappings due to the expressive power of ontology itself.

Lastly, the *map execution* task is the ultimate goal of the whole ontology mapping process. It transforms instances from the source ontology into the target ontology based on the semantic relation discovered during the previous phases. In general, it can be done both offline (static, one-time transformation) and online (dynamic, mapping the ontologies continuously). Frequently, this is done using reasoning tools, which is useful for decision support, which is a field that also makes extensive use of reasoners.

By following these steps, the differences between domain ontologies being used in crisis management can be bridged, and the problems that they pose for providing decision support can largely be addressed.

CONCLUSION

Our current work focuses on two areas of emergency support resources messaging: the development of software that supports the OASIS EDXL-RM standard and the interoperability support of resources message across heterogeneous systems. This will enable CIMS (Crisis Information Management Systems) to help support the disaster response effort and meet the needs of various agencies at different levels in the IMS structure.

Decision making during emergencies is characterized as mission-critical and time-critical. When a catastrophe occurs, no single organization has all the necessary resources to alleviate the damage. Collaborative efforts between various agencies are required. In this paper, an ontology-driven resource-messaging framework that provides decision support during the disaster response period is discussed. Although the development of a structured information format such as EDXL-RM provides a platform for emergency data interchange, the need to support interoperability between various organizations is still a challenge for the ICT sector.

Currently, there is no single or comprehensive methodology that can be adopted to solve the interoperability problem between various systems exchanging ontologies, without major prior knowledge of each other's semantics and mappings. Creating a cohesive solution towards the problem is still posing a challenge to the emergency management ICT sector.

ACKNOWLEDGMENTS

NICTA is funded by the Australian Government as represented by the Department of Broadband, Communications and the Digital Economy and the Australian Research Council through the ICT Centre of Excellence program and the Queensland Government.

REFERENCES

1. OASIS. (2005) OASIS Emergency Management Technical Committee. "Common Alerting Protocol, v. 1.1". OASIS Standard CAP-V1.1, October 2005. <http://www.oasis-open.org/committees/download.php/15135/emergency-CAPv1.1-Corrected_DOM.pdf >
2. OASIS. (2006) OASIS Emergency Management Technical Committee. "Emergency Data Exchange Language Distribution Element (EDXL-DE), v. 1.0". OASIS Standard version 1.0, 1 May 2006. <http://docs.oasis-open.org/emergency/edxl-de/v1.0/EDXL-DE_Spec_v1.0.pdf >
3. OASIS. (2007a) OASIS Emergency Management Technical Committee. "Emergency Data Exchange Language Resource Messaging (EDXL-RM) Version 1.0". Committee Draft 01, 20 February 2007. <http://docs.oasis-open.org/emergency/edxl-rm/v1.0/cd01/EDXL-RM-SPEC-V1.0.doc>
4. OASIS. (2007b) OASIS Emergency Management Technical Committee. "Emergency Data Exchange Language Hospital Bed Availability (EDXL-HAVE) Version 1.0". Public Review Draft 03, 11 October 2007. <http://www.oasis-open.org/committees/download.php/25719/emergency_edxl_have-1.0-spec-pr03.pdf>
5. Iannella, R., Robinson, K. and Rinta-Koski, O. (2007) "Towards a Framework for Crisis Information Management Systems (CIMS)", 14th Annual Conference of The International Emergency Management Society (TIMES), 5th-8th June 2007, Trogir, Croatia
6. Federal Emergency Management Agency (2007). NIMS Integration Center. Resource Management and Typing. <http://www.fema.gov/emergency/nims/rm/rt.shtm>

7. World Wide Web (W3C) Consortium (2004a), OWL Web Ontology Language Overview, W3C Recommendation, February 2004.
8. World Wide Web (W3C) Consortium (1999), Resource Description Framework (RDF) Model and Syntax Specification, W3C Recommendation, February 1999.
9. World Wide Web (W3C) Consortium (2004b), RDF/XML Syntax Specification (Revised), W3C Recommendation, February 2004.
10. Emergency Management Australia (1998), Australian Emergency Management Terms Thesaurus. http://library.ema.gov.au/emathesaurus.
11. United Nations Standard Products and Services Code (UNSPSC), http://www.unspsc.org/, Accessed December 2007.
12. Ding, Y. and Foo, S. (2002) Ontology research and development, Part 2 – A review of ontology mapping and evolving, *Journal of Information Science*, Vol. 28, No. 5, 2007, pp. 375-388.
13. Omelayenko, B., (2002) Integrating Vocabularies: Discovering and Representing Vocabulary Maps, *Proceedings of the 1st International Semantic Web Conference (ISWC)*, Springer, Sardinia, 206-220.
14. Maedche, A. Motik, B., Silva, N., Volz, R. (2002) MAFRA – an ontology mapping framework in the context of the semantic web, *the 3rd International Conference on Ontologies and the Semantic Web 2002*, Siguenze, Spain.
15. Kalfoglou, Y. and Schorlemmer, M. (2003) IF-Map: an ontology mapping method based on information flow theory, *Journal on Data Semantics*, 1,1, 98-127.
16. Doan, A., Madhavan, J. Domingos, P. & Halevy, A. (2003) Learning to Match Ontologies on the Semantic Web, *The VLDB Journal (Special Issue on Semantic Web)*, 12, 4, 303-319.
17. Li, J., (2004) LOM: A Lexicon-based Ontology Mapping Tool, *Proceeding of the Performance Metrics for intelligent Systems (PerMIS. '04)*.
18. Tang, J., Li, J., Liang, B., Huang, X., Li, Y., & Wang, K. (2006) Using Bayesian Decision for Ontology Mapping, *Journal of Web Semantics*, 4, 1, 243-262.
19. Euzenat, J. and Shvaiko, P. (2007) Ontology Matching, Springer, Heidelberg (DE)
20. Yang, K. and Steele R. (2007) A Framework for Ontology Mapping for the Semantic Web, *Proceedings of the 5th International Conference on Information Technology in Asia (CITA07)*