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ABSTRACT

Due to the complex and constantly evolving nature of emergency management (EM), there is little consensus regarding many concepts used to describe informational structure of EM. This limits the efficiency and effectiveness of the decision making processes and can potentially lead to challenges in communication among disaster stakeholders and delays in the execution of emergency responses. This paper presented domain ontology for EM that can be useful to be shared across different emergency agencies and systems. The potential benefits of the proposed domain ontology include enabling better and faster decision making through explicit and shared structure of EM concepts and their relationships. We illustrate how domain ontology can facilitate more effective decision making processes in EM in the context of medical emergency coordination.

Keywords

Emergency management, domain ontology, decision support, process modelling.

INTRODUCTION

Decision making in EM involves selecting and implementing the best course of actions by gathering and analyzing large amount of information from multiple stakeholders. Different emergency agencies generally have their own terminology and application systems. Without a standardized information structure, the decision makers have difficulty aggregating the unstructured data and information from various sources and platforms. These problems can be addressed by developing a domain ontology in EM. In this paper by a *domain ontology* we mean a domain conceptualization, consisting of important concepts and their relationships that are useful in a variety of applications (Gruber, 1993).

The importance of ontology has been increasingly recognized in information systems including knowledge management, natural language processing, information retrieval, intelligent information integration, e-commerce, cooperative information system and database integration (Cardoso, 2007; Su and Ilebrekke, 2002). Cardoso (2007) stated that ontologies have three major uses: (1) to assist in communication between humans; (2) to achieve interoperability and communications for software systems and (3) to improve the design and quality of software systems. The application of ontologies to development of information systems is expected to increase especially with the growing research on the Semantic Web (Maedche and Staab, 2001).

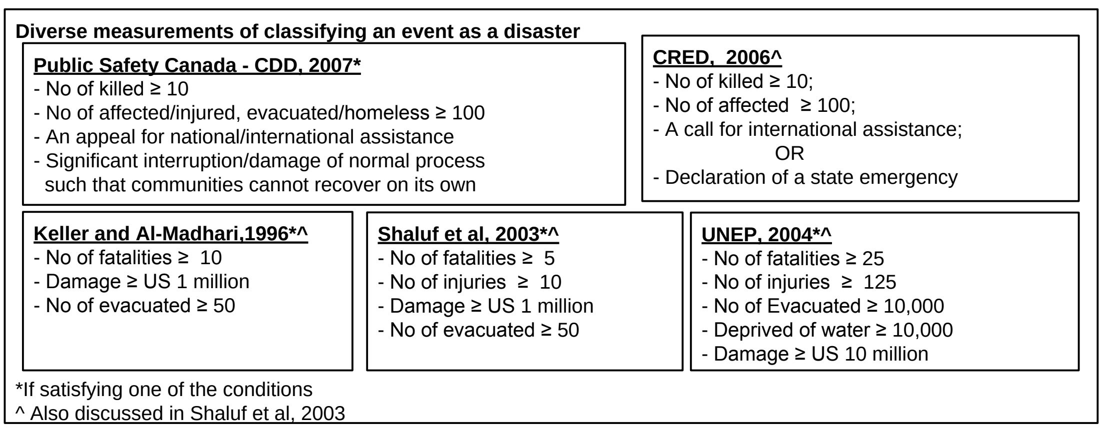
Building domain ontology for EM is a complex and costly task as EM comprises a wide range of fields of knowledge and practice. The task of building an all-encompassing complete and accurate ontology for EM that covers entire range of concepts and their relationships at present remains beyond the reach. However, due to the scalable and extendable nature of ontologies, this challenge can be addressed incrementally. As a first step, this paper introduces an extendable domain ontology that covers major generic concepts in the EM domain widely applicable for all hazards situation. The proposed ontology can be used as information structure for the development of various emergency management decision support systems.

The objective of the paper is two-fold: a) to present a domain ontology for EM and b) to illustrate how the proposed domain ontology can be used to improve decision making in medical emergency coordination. These objectives are achieved through the application of the design science research principles (e.g. Hevner, March, Park and Ram, 2004) that guide the process of building new artifacts and explain how and why a proposed design initiative has potential to address important organization problem.

MOTIVATION FOR RESEARCH

Presently there is little agreement and shared understanding of the major concepts related to the EM domain. Even the term "Emergency Management" has a number of different definitions. For instance, while EM is defined by Federal Emergency Management Agency (FEMA) (2006) as *"organized analysis, planning, decision-making, and assignment of available resources to mitigate, prepare for, respond to, and recover from the effects of all hazards"*, Emergency Management Australia (EMA) (2000) defines it as *"a range of measures to manage risks to communities and the environment."*

Similarly, there is no universally accepted definition of a disaster (Shaluf, Ahmadun and Said, 2003; Sundnes and Birnbaum, 2003). Variations of disaster definitions may hamper the effectiveness of emergency or disaster responses as different terms generally lead to different arrangements and responses. For instance, Burkle (2001) defined disasters as "*catastrophic events* that overwhelm a community's emergency capacity and threaten both the public health and the environment". In contrast, Quarantelli (1997) pointed out that disasters are different from catastrophes. Emergency practitioners also have discrepancies in defining a disaster. United Nations-International Strategy for Disaster Reduction (UN/ISDR) (2008) defined it as "a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources." By comparison, the Centre for Research on the Epidemiology of Disasters (CRED) provides several criteria for the disaster definition including 'a call for international assistance or declaration of a state emergency' (CRED, 2006). Examples of diverse criteria for classifying an event as a disaster are depicted in Figure 1.



CDD: Canadian Disaster Database (CDD)
CRED: Centre for Research on the Epidemiology of Disasters
UNEP: United Nations Environment Programme

Figure 1. Examples of Diverse Disaster Definition Criteria

The concept of vulnerability is also defined differently by emergency practitioners. While vulnerability is defined by EMA as "the susceptibility and resilience of the community and environment to hazards", Sundnes and Birnbaum (2003) separate the term of 'resilience' from the vulnerability definition. A sample of definitions is provided in Table 1.

The risk management process is also defined in the literature in a variety of ways. For instance, UNDP (1992) explained that the process of risk management has two parts: (a) *risk assessment:* the scientific quantification of risk from data and understanding of the processes involved and (b) *risk evaluation:* the social and political judgment of the importance of various risks by the individuals and communities that face them. On the other hand, according to EMA (2000) there are five main components of risk management process: (1) risk management context establishment; (2) risk identification; (3) risk analysis; (4) risk evaluation; and (5) risk treatment. The mathematical "equation" of a disaster risk has been also presented differently in the literature. For instance, UNDP's "equation" of the risk is "Risk = Hazard * Vulnerability"; Arnold (2002) describes it as "Risk = (Hazard * Vulnerability)/Manageability"; Granger (2003) defines it as "Risk = Hazard * Elements at Risk * Vulnerability", while the "equation" from Asian Disaster Reduction Center (ADRC) is "Disaster Risk = function (Hazard, Exposure, Vulnerability)". The priority of risk management may also vary among countries. For instance, the main objectives of risk management in USA have been closely related to limit the liability of insurer and to reduce disaster losses whereas the interpretations of risk management by the researchers from Australia and New Zealand are more focused on hazards and goals of municipalities (McEntire, 2005).

Source	**Definition**
Blaikie, Cannon, Davies and Wisner (1994)	"The characteristics of a person or persons in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard."
EMA (1998)	'The degree of susceptibility and resilience of the community and environment to hazards'
de Guzman, (2003) from ADRC	"The susceptibility of a community to a hazard and the prevailing condition, including physical, socio-economic and political factors that adversely affect its ability to respond to hazards or disaster events."
Krovvidi (1999)	"The degree to which an area, people, physical structures or economic assets are exposed to loss, injury or damage caused by the impact of the hazard."
Noson, L (2004) from Asian Disaster Preparedness Center (ADPC)	"The specific characteristics or conditions of the exposure inventory that increase the chance that a hazard will cause damage, harm, or loss."
Sundnes and Birnbaum (2003)	"The susceptibility of the population and environment to the type (nature) of the event' (i.e. Vulnerability = 1 – Resilience)."
United Nations Development Programme (UNDP) (1992)	"The degree of loss (for example, from o to 100 percent) resulting from a potentially damaging phenomenon."

Table 1. Examples of Different Definition of Vulnerability

In summary, the absence of standardisation of EM concepts definition not only hampers the effectiveness of emergency prevention but may also lead to miscommunication and problems when responding to actual events that involve multiple emergency agencies from various states or nations. Ontology in EM could provide a means to solve this problem. Ontologies can provide a unifying conceptualisation in EM, using which the different emergency stakeholders can work together more effectively as they shared the same understanding of the EM concepts. The process of development of such a domain ontology for EM is discussed in the next section. This process was followed in collaborative effort involving the EM domain expert in developing a prototype ontology presented in this paper.

DOMAIN ONTOLOGY FOR EMERGENCY MANAGEMENT

We separated the building process of EM domain ontology into seven major stages as follows:
Stage 1: Objective and Planning - At the first stage, we established a strategic plan that sets out the objective, scope, potential usage, intended users, assumptions and limitations of the proposed domain ontology. The scope of the domain ontology is limited to generic concepts of EM and their relationships that are applicable for any types of hazard. It was intended to be used by any types of emergency stakeholders for knowledge sharing and reuse. The proposed ontology can also be used to:

(a) provide foundation for further development of ontologies for EM;

(b) provide a repository for general knowledge about EM domain that assists the development of new systems for EM;

(c) facilitate communication between different emergency agencies;

(d) promote interoperability between different systems used for EM; and

(e) integrate the proposed ontology with process modelling for decision support in EM.

Stage 2: Knowledge Acquisition - The required knowledge was acquired from the emergency domain experts; public reports; internal organisation report; research journals and papers; and emergency best practices and standards (e.g. FEMA, EMA, ADPC, ADRC and UNDP). The knowledge about structure of various dimensions of EM was encapsulated into an "Integrated Framework for Comprehensive Collaborative Emergency Management" (IFCCEM) (Sujanto, Ceglowski, Burstein and Churilov, 2008). The IFCCEM can be used as a foundation to build the proposed domain ontology. It assists in identifying concepts in EM and their relationships.

Stage 3: Ontology Design - This stage includes determining design principles and criteria to build ontology, choosing ontology language and tools and establishing methodology that address the objective of the domain ontology.

- **Design principles**: The design principles as summarized by Corcho, Fernandez-Lopez, and Gomez-Pérez (2001) were applied in building the proposed ontology. These include Gruber's design criteria (1) clarity, (2) coherence; (3) extendibility; (4) minimal encoding bias; and (5) minimal ontological commitment as well as by other researchers that include (6) ontological distinction principle; (7) diversification of hierarchies; (8) modularity; (9) minimization of the semantic distance between sibling concepts and (10) standardization of names. These principles could also be used as a benchmark for ontology evaluation.
- **Language**: OWL Web Ontology Language-Description Logic (OWL-DL) was chosen as the ontology language as it has more facilities for expressing meaning and semantics (World Wide Web Consortium (W3C), 2004).
- **Tools**: Protégé-OWL was utilized as the tool to build the proposed ontology. Protégé OWL is a plug-in extension to the Protégé platform for building ontologies in OWL that aims to make Semantic Web technology available to a wide range of developers and users (Knublauch, Fergerson, Noy and Musen, 2004)
- **Methodology and Guidelines**: While there have been a numerous methodologies presented in the literature, no methodology has proved to be universal because of domain restriction, data type applicability, linearity constraint and tool dependency, which may hamper the reuse of ontologies (Cristani and Cuel, 2004). For the purpose of ontology, we applied elements of existing methodology (i.e. Methontology) and the guidelines of building ontology suggested by Noy and McGuinness (2001) and Rector, Drummond, Horridge, Rogers, Knublauch, Stevens, Wang and Wroe (2004) and tailored them to meet our objective.

Stage 4: Ontology Building - The building of ontology can be performed from scratch or by reusing other existing ontologies (Pinto and Martin, 2004). As there are no publicly available ontologies in EM for reuse, we have built the proposed domain ontology from scratch. A snapshot of the proposed domain ontology is depicted in Figure 2.

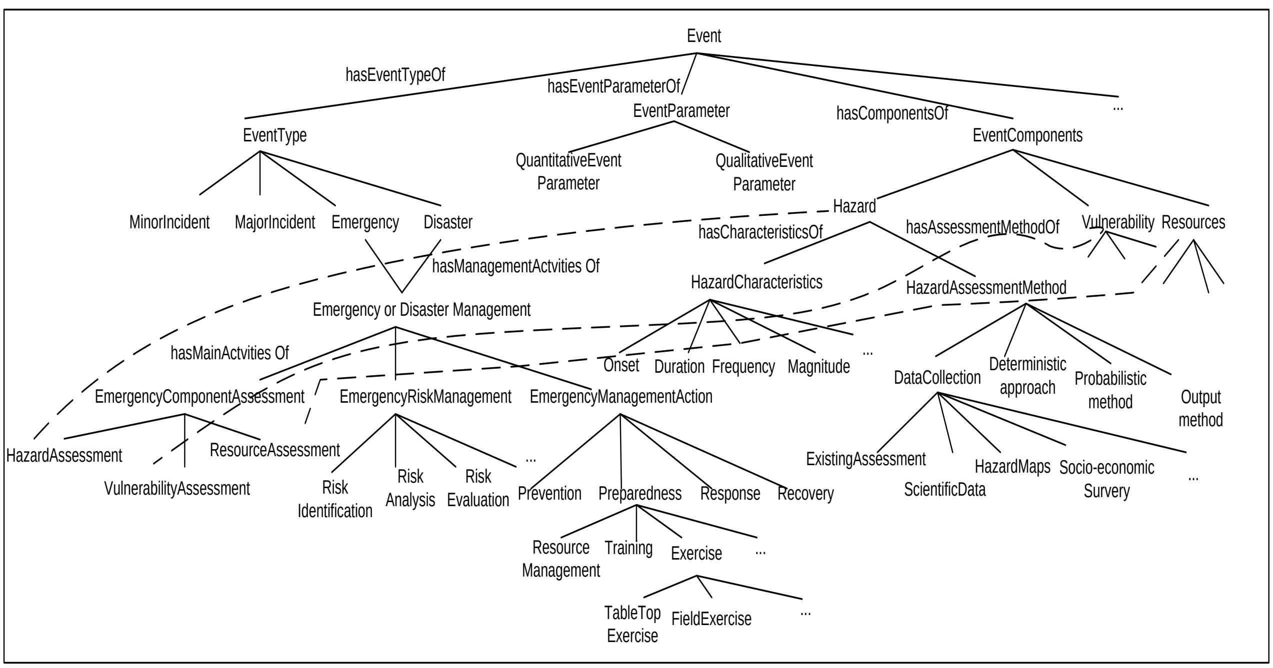


Figure 2. A Snapshot of the Proposed Domain Ontology for EM

In this ontology, an *event* is "an occurrence that has the potential to affect living beings and/or their environment" (Sundnes and Birnbaum, 2003). Event has three main components that are *hazard*, *vulnerability of population* and *coping resources*. If the coping resources are sufficient to manage the impact of hazard and the vulnerability of population, then the type of event is either minor or major incident; otherwise it is an emergency or disaster. The occurrence of emergency or disaster events will trigger the activation of emergency management plans. An event can be measured using quantitative and qualitative parameters. Quantitative parameters include number of dead, number of missing, number of injured, number of homeless, cost of damages and so forth. Examples of qualitative measurement include the extent of health and safety problem, emotional and psychological impacts.

EM has six major activities (1) strategic policy and program establishment; (2) emergency components' assessment (i.e. hazard, vulnerability and resources); (3) emergency risk management (i.e. risk management context establishment; risk identification; risk analysis; risk evaluation; and risk treatment as suggested by EMA); (4) EM actions (i.e. Prevention, Preparedness, Response and Recovery); (5) evaluation and improvement; and (6) communication, consultation and documentation. These main activities cover a large number of concepts in which they are closely related. Hence, the importance of modularisation was recognised and applied in this ontology to facilitate a better reuse, maintainability and evaluation (Doran, 2006; Rector, 2003).. The modules of the proposed ontology include hazard, vulnerability, emergency risk management, emergency management actions, and so forth. A number of OWL files are created using Protégé-OWL to reflect these modules (see Figure 3 as an illustration).

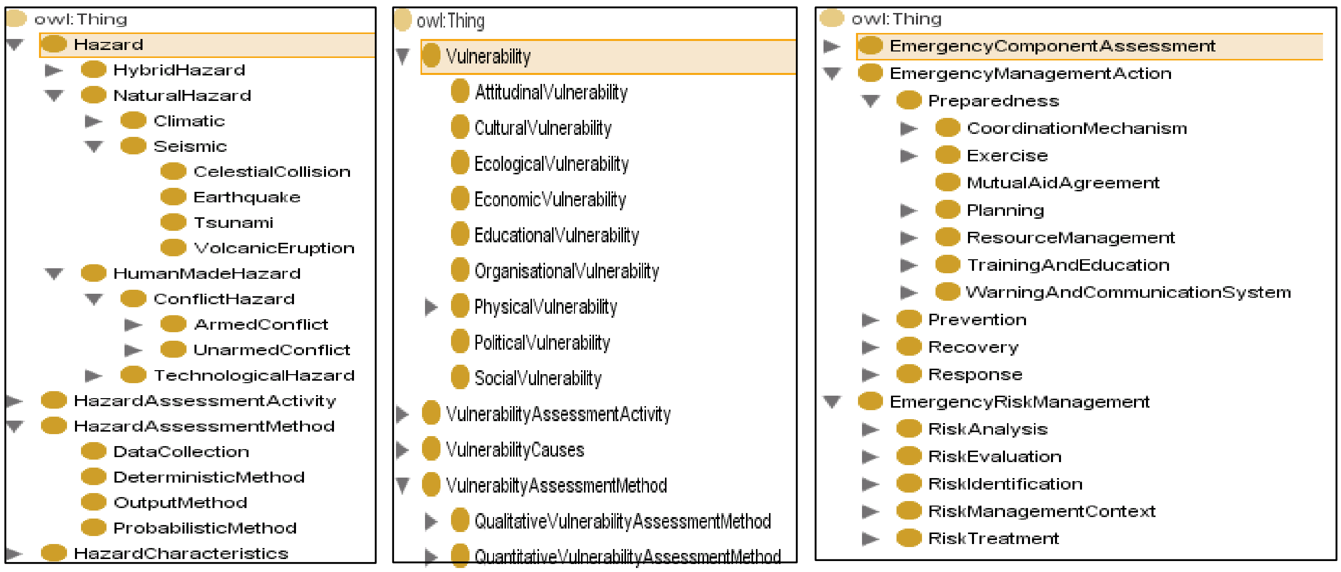


Figure 3: Examples of Modules in the Proposed Domain Ontologies

Once the proposed ontology is fully developed and satisfies the technical evaluation and user assessment, we plan to reuse existing ontologies on medical domains such as ontologies for drugs and integrate them as part of medical responses in EM to complement it in respective areas.

Stage 5: Ontology Validation and Evaluation - There are five dimensions in which the proposed domain ontology should be validated and evaluated prior to its implementation. These include (1) *structure and design* of the domain ontology to ensure it meets the pre-defined design principles or criteria including clarity, coherence, extendibility, minimal encoding bias and minimal ontological commitment (Gruber, 1995); (2) *contents* of the domain ontology (i.e. concepts, taxonomy and relations) to ensure they are consistent, precise and useful (Gomez-Perez, 1995); (3) *technologies* used to build the ontology (e.g. software environment and tools) to ensure they are reliable, support the content evaluation and allow easiness of its integration with other environments; (4) *documentation* to ensure adequate documentation for maintenance and reuse; and (5) *applicability* to ensure the ontology is logical and practicable for knowledge sharing and reuse. The proposed ontology has been evaluated according to the first three dimensions and is in the process of being documented accordingly. The applicability testing has been performed at a conceptual level in the context of medical emergency coordination as described in the next section.

Stage 6: Ontology Implementation - The main aim of ontology implementation is to become an integral component of the information system (Dapoigny, Benoit and Foulloy, 2002). In addition, the domain ontology can be implemented as a basis for automatic generation of knowledge databases embedded in intelligent instruments (Dapoigny, Benoit and Foulloy, 2002; Musen, 1998). In the case of Musen's EON project, domain ontology was used as a guide to the execution of large numbers of general software components such as to define database schema and semantics of knowledge acquisition tools (Musen, 1998). As previously mentioned, there are a range of options for the implementation of domain ontology for EM. In this paper we use it as part of DSS for medical EM as described in the next section.

Stage 7: Ontology Maintenance - Ontology evolves over time with changes in any of three elements: domain, conceptualization and explicit specification (Noy and Klein, 2004). While *changes in the domain* are very common as the real world is dynamic; *changes in conceptualization* can be due to a change in viewpoint of the world and usage perspective;

and *change in the explicit specification* can be caused by translating an ontology from one knowledge-representation language to another that have different syntax, expressivity or semantics. The proposed ontology would be updated when any of these changes occur.

APPLICATION OF THE DOMAIN ONTOLOGY FOR DECISION SUPPORT IN MEDICAL EMERGENCY COORDINATION

Emergency responders depend on the availability of information to guide them in making timely and effective decisions. However, presently the current decision support systems (DSS) are unable to transmit the data freely and quickly due to incompatible information systems and different vocabularies (Thompson, Altay, Green III, and Lapetina, 2006). The proposed domain ontology aims to assist the integration of disaster information from different systems and applications. Ideally, DSS, executive support systems, and other information systems should be developed based on common domain ontologies and process models, which have been formally and systematically developed involving multiple sources of knowledge and validated by domain experts (Figure 4). Such systems would result in more efficient decision making processes.

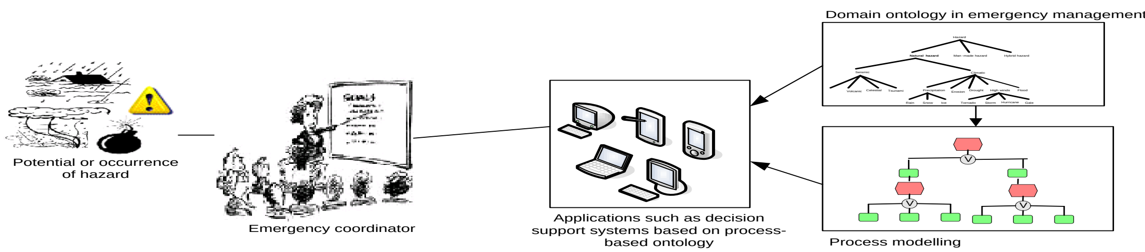


Figure 4. Integrating Process Modelling and the Domain Ontology for Decision Support

We illustrate the relationship between the domain ontology and process modelling for decision support, based on medical emergency response activities in Victoria, Australia as this research is conducted in collaboration with Health Displan, Victoria, Australia (formerly Medical Displan). The modelling of decision making process in medical EM was limited to coordination of all necessary health related activities during an emergency event associated with potential mass casualties.

Typically, the decision-making in coordinating health response activities consists of five main steps: (1) notification; (2) context assessment; (3) resource analysis and allocations; (4) on-scene and off-scene management and (5) definitive patient care (Figure 5).

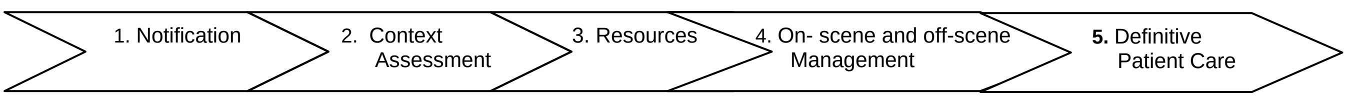


Figure 5. Typical Decision Making Process in Coordinating Medical Response Activities

1. **Notification** - The decision making process is initiated when the medical response coordinator is notified about an event, *actual or imminent*, which endangers or threatens the community and/or environment and may require a significant medical coordinated response.

2. **Context Assessment** - Prior to make decision on the activation of the State Plan, the emergency medical coordinator has to perform context assessment that includes assessing hazard, vulnerability of the population and medical resources at scene.

3. **Resources** - If the existing medical resources at scene are adequate and additional assistance is not required, the medical emergency coordinator will stay alert awaiting a follow-up report that confirms the event is cleared. If local resources are not sufficient or if the incident is escalated to the emergency or disaster status, the medical coordinator have to estimate, gather and allocate the required medical resources based on the context assessment to ensure they are sufficient to meet the needs of both victims and emergency responders.

4. **On-scene and off-scene management** -The complexity of on-scene management depends on the scale of incidents. In case of large scale events, assistance from other States and International organizations may be required. The main responsibilities of on-scene coordinator include triage, injuries treatment, transport coordination, mental health support, public health relief and liaison with other emergency services. The off-scene medical coordinator acts as an advisor to the on-scene medical coordinator and is also in charge with coordinating hospital arrangement.

5. **Definitive Patient Care -** The activity medical emergency coordination is typically ended with definitive patient care. Prior to closing the emergency case, the representatives of emergency response teams are normally gathered for briefing in which their feedback are obtained and documented for evaluation and improvement.

Figure 6 shows how the main decision processes for medical emergency coordination can be modeled with Event-driven Process Chain (EPC) and linked to the domain ontology for decision support. EPC is a widely used technique for process modelling that has been used in SAP R/3 (Davis, 2001). EPC consists of three basic components: 'events' that are preconditions of functions and can be the result of functions; 'functions' that represent the activities or tasks that are carried out as part of business process and 'logical connector' that include conjunction (AND), disjunction (OR) and antivalenz (XOR) (Brain, Seltsikas, Tailor 2005; Davis, 2001). Such DSS provides step-by-step guidelines and incorporates important factors that should be identified, analyzed and evaluated prior to make a decision. In the event of emergency, the DSS guided the decision maker to perform assessment on hazard, vulnerability, resources, impacts of events and other potential threat (Table 2).

Hazard	Vulnerability	Resources
• Type of Hazard • Characteristics? Likely duration? Predictability? Close to happen? Secondary hazard?	• Special population? Elderly, disabled, children, pregnant woman, victims with routine medication, ethnics. • Vulnerable building? Collapsed building, fire, flood, Smoke.	• Which emergency services have attended the scene? • External resources required? • Special resources?

Potential Health Impact	Other Threats
• Environmental effect? Heavy dust, toxic gas, air pollution, chemical spills • Public health? Food shortage, homeless, loss of utility, hygiene.	• Weather condition? Hot, cold, rainy • Darkness soon? Complex scene? • Split sites? Electrical cables?

Table 2. Examples of Emergency assessment using the propose ontology

Since all these concepts related to the emergency assessment and their relationships are pre-defined in the proposed domain ontology, the users' actions would be better coordinated and consistent in their expected outcomes. In relation to the decision on the resources, DSS will guide the decision makers to consider a number of factors including (i) anticipation of duration of scene care; (ii) types of injuries; (iii) capacity of existing local resources; (iv) the need for external resources to back up the requirements; (v) the need for special resources for distinctive patient such as in the cases of burned patients, hazmat incidents and amputation; (vi) the needs of rescuers including their personal need, health, safety and hygiene; and (vii) the supplies of medical and drugs including routine medication for the victims. In relation to the on-scene management, the domain ontology also covers important concepts such as triage, clinical management, transport coordination, public health protection and mental health care (Figure 6). Due to paper size limitation, Figure 6 only shows a snapshot of the domain ontology in EM and process modelling in medical emergency coordination. From this brief overview the potential benefits from having common grounds for supporting such complex decision situations is pretty evident.

CONCLUSION

The lack of conceptual framework and common information structure in EM has been acknowledged for the last decades. We proposed and developed a relatively broad ontology for EM to address this problem. The purpose of this ontology is to provide explicit conceptualization of the EM domain that can be shared across different emergency stakeholders and platforms. Such ontology can be used to improve information reuse and interoperability among different emergency agencies and systems.

We also investigated the relationship between the domain ontology and process modelling and how they can be integrated for the purpose of decision support in medical emergency coordination. The proposed domain ontology can also be used to assist the development of other information systems to assist in EM. More generally, we agree that the absence of commonly agreed methodologies for creating ontology is an area where some additional research is required (Cristani and Cuel, 2004), however, in this paper we have described some approaches in this direction and an integrated framework presents as a solid start in this direction.

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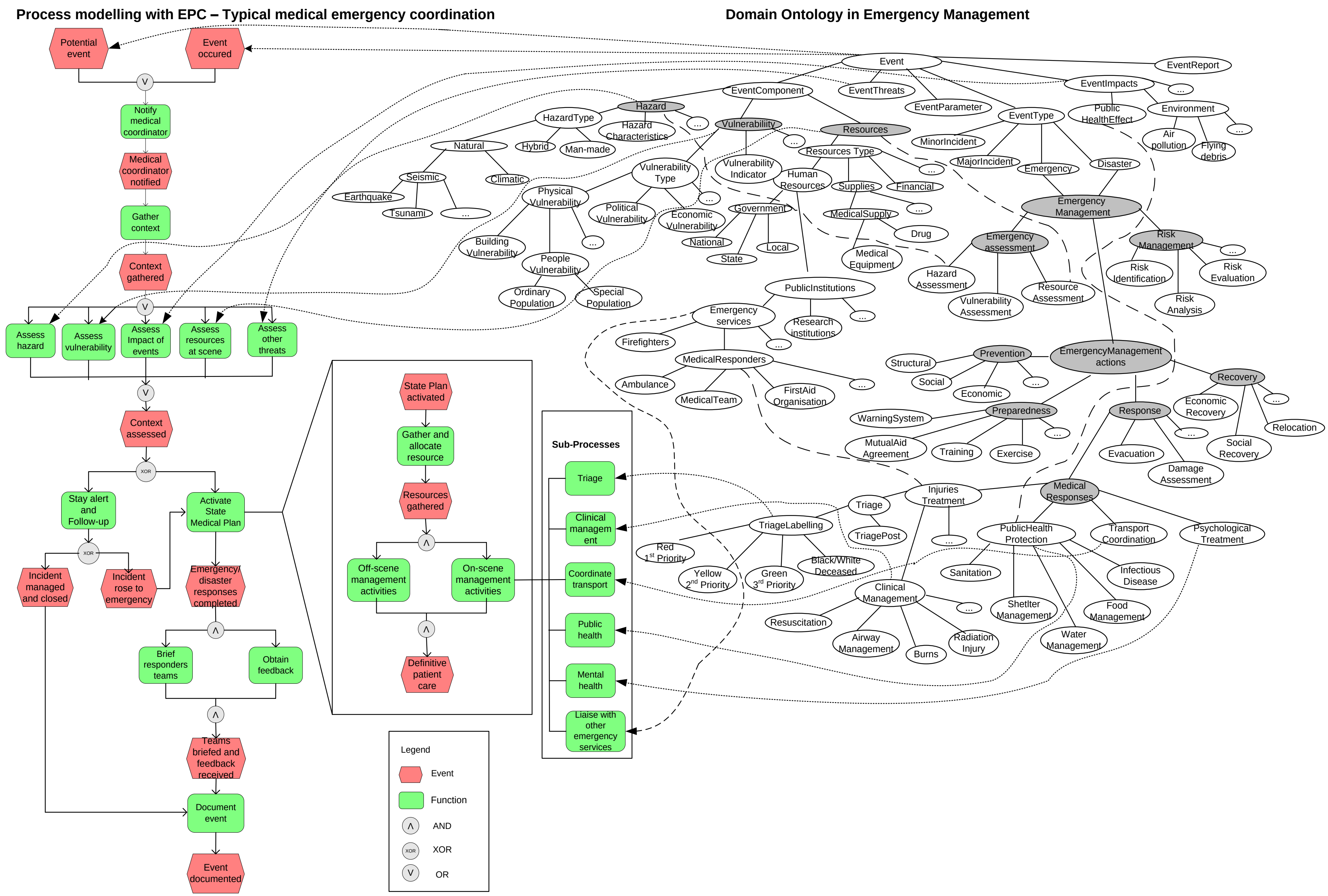

Figure 6. Illustration of the Link between Domain Ontology and Process Modelling for Decision Support in Medical Emergency Coordination

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