Using Ontology for IT-enabled Comprehensive Management of Mass Gatherings

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Abstract. Management in mass gatherings is a complex process that consists of three major phases: planning, operational response, and debriefing. Each of these phases involves information exchange between different agencies involved in planning and running the event. It has been widely recognized that the data quality and access to critical information impact on the efficiency of the response and overall effectiveness of the emergency management. Therefore, there is a need for solid understanding of the information needs of the agencies pertinent to designing efficient decision support systems, which are truly integrated into the context of business environment and facilitate IT-enabled work of the personnel organizing and running mass gathering events. Introduction of such ubiquitous systems depends on availability of ontology of the problem domain, which provides a common ground for information integration, gathering and exchange. We propose a conceptual architecture for ontology-based, IT-enabled decision support that extends to all phases of mass gatherings. As an example, we describe a case-based reasoning (CBR) system which takes advantage of such an ontology and ontology reasoning and can be used for prediction of medical workload and providing better understanding of mass gathering events during planning or training of new staff.

Keywords. Ubiquitous decision support systems, decision making, ontologies, ontology reasoning, mass gatherings, medical emergency management

1. Introduction

Mass gathering event can be defined as an event in which at least 1,000 people attend for an extended period of time [1]. At such events, a large number of people gather and there is a potential for incidents including injuries and other health hazards. Therefore mass gatherings require careful planning to ensure that adequate and appropriate medical care and response is provided to attendees [2].

Medical emergency management in mass gatherings is a complex process that can be divided into three major phases: (a) planning, (b) operational response, (c) debriefing and evaluation. Each of these phases involves information exchange between different agencies responsible for planning and/or running the event. It has been widely recognized that access to critical information significantly impacts the
efficiency of the response and overall effectiveness of the emergency management [3]. Therefore there is a need for designing good decision support systems, which are truly fused into the context of business environment and facilitate IT-enabled work of the different agencies running mass gathering events.

Today the prevalence of the Internet, mobile communication, and smart devices in conjunction with ever-growing fusion of IT into information systems (IS) [4] presents an exciting opportunity to improve the mass gathering tasks, particularly emergency medical response [5]. This IT-enabled work can benefit from utilizing ontologies for standardization of domain concepts and terminology as the basis for effective data sharing. The ontology also enables maintaining consistency and uniformity of stored data that is shared and managed by different agencies. It can also facilitate the use of other intelligent technologies by handling underlying semantics of information exchange.

Reviewing data collection studies [2, 6-9] shows that in mass gathering events, data can be collected and recorded using different terminology. For example, the information about the venue can be stored under the term ‘name’, ‘location’, ‘venue’, ‘event venue’, ‘address’, etc. The lack of a standard data collection structure also introduces another challenge that can be alleviated through using a common vocabulary. When the mass gathering data stored in several databases (data repositories) use different terminology to describe the same concept, the task of data management and integration will be extremely difficult and it can reduce the accuracy of results where the semantic discrepancies and mismatches are present. The use of a domain ontology to represent the domain concepts and terms in a unified manner in conjunction with its reasoning capabilities can address the challenges discussed above.

We have constructed and demonstrated validity of the domain ontology for Medical Emergency Management in Mass Gathering (EMMMG) [10]. This ontology currently named DO4MG (Domain Ontology for Mass Gatherings) [11], has been revised and validated, and provides a comprehensive representation of the mass gathering (including medical emergency management) concepts and their relationships.

In this paper we illustrate how such ontology can be used in overcoming information fusion and management problems in mass gatherings. We propose an architecture for ontology-based, IT-enabled decision support that extends to all the phases of mass gatherings. As an example we describe a CBR system which takes advantage of such an ontology and can be used for prediction of medical workload and providing better understanding of mass gathering events during training.

2. Understanding Complexities of Management of Mass Gatherings

Organizing a successful mass gathering is complex and includes several stages and a variety of tasks which require participation of different agencies and services. WHO (World Health Organization) [12] refers to three main phases of mass gatherings which include planning, operational, and evaluation phases. Burdick [13] suggests that WEM (Wilderness Event Medicine) which provides the healthcare response at any remote and discrete event involves three phases including pre-event planning, medical treatment at the event, and post-event tasks. From reviewing mass gathering literature [6, 7, 9, 12, 13] it can be concluded that in general mass gathering activities and tasks can be grouped under three phases of pre-event, during-the-event and post-event phases. The pre-event phase typically involves planning the event. The during-the-event phase is
the operational stage where medical response and treatment are provided. The final stage of mass gathering usually entails debriefing, evaluation and auditing of the event [2]. Figure 1 shows the three stages of mass gatherings.

![Three main stages of mass gatherings.](image)

With regard to pre-event planning, ACEP (American College of Emergency Physicians) [14] provides a schedule containing 13 tasks that relate to the provision of emergency medical care in mass gatherings. In [2], this schedule has been extended into 33 tasks including post event tasks such as Debrief and Post Event Audit. However, some of the tasks (in both schedules) such as ‘Event Planning Meeting’, ‘Order uniform clothing/Procure + check clothing’, etc cannot be automated and need to be performed by humans. Inspired by these schedules and based on current literature of mass gatherings, we have listed a set of tasks and activities that can be supported by IT-enabled tools and applications in Table 1. It is noteworthy mentioning that this list is not inclusive and can be easily extended by further IT tools. In this paper, we describe the ontology-based CBR application that we have developed.

**Table 1. The mass gathering main tasks (adapted from [2, 14])**

<table>
<thead>
<tr>
<th>Stages</th>
<th>IT Tools</th>
<th>Ontology Role</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planning</strong></td>
<td>- Software applications for easy data entry</td>
<td>- To standardize all the definitions using a unified vocabulary</td>
</tr>
<tr>
<td></td>
<td>- Visualization of event site using Google Map</td>
<td>- enabling filtering</td>
</tr>
<tr>
<td></td>
<td>- CBR application assists trainees to enter the details of an event in the query and compare with the retrieved cases (historical data) *</td>
<td>-Includes all the elements of a venue (external and internal) facilitates filtering and search provides a hierarchical view</td>
</tr>
<tr>
<td></td>
<td>- Estimation of workload based on historical data</td>
<td>-Increasing accuracy of CBR by resolving the discrepancies of data during the retrieve phase *</td>
</tr>
<tr>
<td></td>
<td>- Defining event</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Visit event site</td>
<td></td>
</tr>
<tr>
<td><strong>Operational</strong></td>
<td>- Real-time DSS</td>
<td>- Standardization of vocabulary used</td>
</tr>
<tr>
<td></td>
<td>- Location-aware monitoring on mobile phones</td>
<td>-Increasing effectiveness of communication</td>
</tr>
<tr>
<td></td>
<td>- Real-time visualization of high medical demands on the venue map with injury details</td>
<td>Improving decision making</td>
</tr>
<tr>
<td></td>
<td>- Monitoring the event and crowd</td>
<td></td>
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<tr>
<td></td>
<td>- Real-time interactions and communication between emergency services</td>
<td></td>
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<tr>
<td><strong>Debriefing</strong></td>
<td>- Software applications for recording event data (consistent with phase1 CBR’s revise stage*)</td>
<td>Improving management, integration and storage of data by using a unified data structure</td>
</tr>
<tr>
<td></td>
<td>- Recording event data</td>
<td>- standardization of recording data</td>
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<td></td>
<td>- Evaluation</td>
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</table>

*This application has been developed and described in this paper.*
In [11], we introduced our mobile location-aware decision support system. This work is being extended by integration of ontology (DO4MG) and reasoning tools. The other listed applications are as part of our ongoing research.

3. Importance of Common Ontologies for Decision Support

Ontologies as a conceptual model provide a formal representation of concepts and their relationships within a certain domain that can be used for knowledge sharing [15]. Over the years, ontologies have been used to establish ‘explicit understandings of the structure of complex problems’ and to facilitate data integration and interoperability [16:475). For example, the EON decision support [17] applies an ontology for representing clinical protocols such as drug therapy in order to enable a shared and standard representation of all the data elements. Dzemydiene and Kazemikaitiene [18] include ontologies in a decision support system to improve crime investigation by providing a standard framework to collect information and establish the conditions to achieve more effective decisions. Another example is OntoWEDSS [15], which integrates ontologies into DSS to improve modelling of wastewater treatment processes and facilitating the communication among different components of the environmental DSS. OIDSA [19] is an intelligent decision support agent that uses ontologies for improving project monitoring and control of capability maturity model integration. However, these ontology-based works do not focus on the benefits of ontologies and ontology reasoning to deal with the issue of data discrepancies which is introduced when data is collected and also shared by different parties and agencies. These works do not provide an approach for integrating ontology into multiple phases and business processes to improve information sharing and filtering.

In Delir Haghighi et al. [11] we introduced a domain ontology, named DO4MG to provide a consistent and comprehensive view on the problem domain that can be used by all concerned stakeholders and can be applied to all the phases and tasks of mass gatherings. We have applied the DO4MG to a number of DSS for mass gatherings to validate the potentials and benefits of ontologies. In this paper, we demonstrate how an ontology-based DSS and ontology reasoning can improve data integration and resolve data inconsistencies. As a proof of concept, the following section discusses the ontology-based CBR application that we have developed.

4. Architecture for Intelligent Decision Support for Management of Mass Gatherings

As discussed earlier, mass gatherings consist of three stages and a series of activities that are mostly IT-enabled work. The consistency and standardization of operations through all these phases are crucial to improve the overall results and effectiveness of medical provision. This can be mainly achieved by utilizing a common and unified data/knowledge structure that can be shared through all the phases. A domain ontology (i.e. DO4MG) covers all the mass gathering concepts and has the features to support relationships, annotations, properties and particularly querying and reasoning. Integrating a common ontology into all the IT-enabled work of mass gatherings provides consistency and effectiveness in all the activities, facilitates data entry, management, filtering and integration, avoids discrepancies, and enables mapping of
past and present data to discover any mismatches and unexpected situations (e.g. sudden increase in the number of patients with food poisoning). Figure 2 illustrates an architecture of mass gathering phases and integration of ontology into these phases.

In the following section, we show how IT-enabled tools can be fused with information systems and ontologies as a representation of domain knowledge. We discuss our CBR application that uses ontology to improve accuracy of decision support and enables avoiding inconsistencies that can arise from using different vocabularies during data collection in mass gatherings.

4.1. Case-Based Reasoning with Ontologies

Case-based reasoning (CBR) is a method used for problem solving and decision making that uses past cases similar to the current situation to solve the new problem [20, 21]. CBR was introduced by Schank [22] as one of subfields of Artificial Intelligence. Since then CBR has been successfully applied to DSS in different domains including emergency management. Examples include the CBR application for emergency commanding and decision-making using fuzzy attributes [23], the CBR and Rule-Based Reasoning (RBR) model for Emergency Decision Making (EDM) [24], Early-warning System Design for Collegial Mass Emergency [25] and a case-based group decision support method for emergency response [26].

4.1.1. The Data Inconsistency Challenge

The case-based reasoning approach includes four main stages including Retrieve, Revise, Reuse and Retain [21]. During the Retrieve stage, the query entered by the user is compared to past events stored in a database using similarity functions and the most similar cases are retrieved. Similarity functions are selected and used according to the data type of data (e.g. numeric or strings). When the data type is string (i.e. a series of...
characters), the similarity functions typically perform comparison without considering semantics and meaning of words.

Reviewing the literature for mass gathering shows that different emergency services agencies use different attributes/terms to represent the same concept [2, 6, 8, 9, 27]. We provide three examples to elaborate on this further.

The term ‘usage rate’ and ‘MUR (Medical Usage Rate)’ refer to the number of patients treated at an event [6]. These two terms can also be interchanged with the term PPR (Patient Presentation Rate) [7]. PPR means patients presenting per 1,000 spectators.

Another example of the terms that represent the same or a very similar concept to ‘motor racing’ include ‘auto racing’ [6], ‘motor sports’ [2], ‘motor race’ [27], ‘automobile races’ [8].

Crowd type is one of the important concepts in the mass gathering context which is defined as an environmental descriptor of the demographics of a crowd [28]. According to Berlognghi et al. [29], Emergency Management Australia (1999) [30] categories crowd type into Ambulatory, Disability/Limited Movement, Participatory, Cohesive/Spectator, Expressive/Revelous, Aggressive/Hostile, Escape/Trampling, Dense/Suffocating, Rushing/Looting, Demonstrator, and Violent. The ‘Ambulatory’ type means being usually calm and walking. It is also defined as the opposite of the ‘seated’ crowd with the meaning of being able ‘to move around or participate in the event’ [31].

When the data from several events need to be integrated or used collectively, the inconsistencies and discrepancies between different data sets can complicate data integration and management (i.e. storage, retrieve, query, etc). In the context of case-base reasoning, this can result in retrieval of incorrect cases. If the recorded data and the query entered by the user use different terms/attributes but have the same meaning (i.e. they are synonyms), they will not be matched correctly. This will reduce the accuracy and effectiveness of the case-based reasoning and decision support. To address this issue, ontologies and ontology reasoning provide an elegant solution by providing richer queries that could be performed using concept based similarity functions [32, 33]. Ontologies provide a common and unified vocabulary to describe a domain of interest using the major concepts and terms applied in that domain [15]. They enable semantic reasoning and can represent lexical knowledge. Integrating ontologies into the reasoner of CBR can improve the efficiency and effectiveness of case-based reasoning by resolving semantic conflicts and terminological differences.

5. Ontology-Based CBR for Estimating Workload in MG

To demonstrate how ontology can improve decision making in CBR applications, we have developed a case-based reasoning prototype. The prototype is implemented using the jCOLIBRI2 framework in Java. jCOLIBRI2 is an open source tool that provides supports for development of different CBR applications [34]. The jCOLIBRI2 framework provides support for ontology-based systems by using the Onto-Bridge libraries and Pellet2 reasoner [32, 33].

In our context the ontology-based CBR application enables the user to enter the details of a future event and compare their estimated workload (i.e. patient presentation

http://clarkparsia.com/pellet/
rate) for an event to the similar events. Estimation/prediction of the patient rate in mass gatherings is highly important and useful to determine the workload of medical personnel (e.g. nurses, first aiders, etc) that is required at these events [9]. The developed CBR application aims to assist medical emergency personnel with decision making when predicting the number of patients for a ‘problem case’ (i.e. a future event) and provide them with better understanding of mass gathering events.

The data repository used in this application includes 201 records of different mass gathering events which occurred over a period of 12 months. The data was collected by St John Ambulance Australia personnel (2010) and has previously been used for building a predictive model [7] and for identifying the important attributes when predicting injury/illness rates [35]. The CBR application operates through the common CBR stages including querying, specifying similarity functions, retrieving cases, and finally revising and storing cases. The next subsection describes these stages in more detail.

**Querying**

At the first stage of case-base reasoning, the user enters the details for a future mass gathering event and predicts the patient presentation rate (PPR) and transportation to hospital rate (TTH) [7]. During this stage, the application allows the user to select some of the concepts directly from the DO4MG ontology (as shown in Figure 3). In this example, the event type is ‘MotorRacing’ that is a subclass of ‘GatheringType’.

![Figure 3. Creating and querying events and selecting concepts from the ontology.](http://www.stjohnqld.com.au/index.php/en/home)

Figure 4 shows different similarity functions provided by jCOLIBRI2. We have added extra functions (e.g. ThresholdDouble, EqualIgnoreCase) and also made necessary changes to other functions to tailor them according to our system.

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requirement. For example, ontology reasoning is performed on subclasses rather than instances. At this stage the number of the retrieved cases (K) is entered (i.e. three).

Retrieving Cases Using the DO4MG ontology
At this stage, a ‘problem case’ entered by the user is compared to the case base (i.e. stored data) by using the selected similarity functions to retrieve the most similar cases. We have used the DO4MG ontology to improve this stage and accuracy of retrieved cases by resolving the discrepancies between the stored data and the user entered data. DO4MG is developed in Protege which provides several options to create synonyms. We have used annotations (i.e. labels) to create different synonyms for a concept. Figure 5 shows an example where different labels are used to represent ‘MotorRacing’.

Figure 5. An example of using labels for creating synonyms in DO4MG.

Figure 6 shows the use of one of the above-mentioned labels in our recorded data. As the figure shows the MGtbl.sql file uses the term ‘MotorSports’ for the event type.
Using the ontology and defined synonyms, the application is able to match the query correctly to the stored cases such that the synonyms will not be ignored. Figure 7 shows the three retrieved cases. In this example, the ’MotorSports’ attribute used in the data set has been matched correctly to the MotorRacing concept in the DO4MG ontology because it was defined as its synonym (shown in Figure 5).
Revising Cases
The stage of CBR is revising. This step allows adapting the retrieved cases according to the attendance and temperature which are two important factors regarding injury rates [6, 9]. The adapted cases can be stored in the case base for future reuse [32, 33].

6. Conclusion and Future Work

Mass gatherings are common events, e.g. sporting events, concerts, etc, that typically attract large crowds of people. These events typically involve participation of various medical emergency agencies (e.g. first aiders, nurses, police, ambulances, etc) who are geographically spread across the venue. These agencies and team members may usually use different terminology and concepts for communication. In mass gatherings, establishing effective and efficient interaction among participating emergency services is extremely important for the provision of timely medical response and treatment [36]. The lack of a standard knowledge structure and unified domain vocabulary in such environment could limit the effectiveness of communication and coordination, leading to delays in responding to patients [36, 37]. The DO4MG ontology [11] was introduced to provide a common and unified knowledge structure of the mass gathering concepts. Such standard representation of domain knowledge in conjunction with ontology reasoning tools enable effective coordination and interaction between different emergency agencies and facilitates storage, integration and querying of recorded data in the events.

In this paper we demonstrated how applying DO4MG and ontology reasoning techniques to different phases of mass gatherings provides an elegant solution to deal with communication challenges among various emergency services as well as the problems of management and integration of mass gathering data. As part of future research we are working on extending our location-aware decision support for medical emergency management [11] by factoring in additional contextual and real-time information to monitor crowd mood, and intend to arrange trials with domain experts to test our work in real scenarios. We also aim to provide intelligent user interface that enables monitoring the event by visualizing the types and numbers of patient injuries and symptoms on dynamic maps (i.e. Google maps) on Android mobile phones.

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References


