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Development and evaluation of ontology for intelligent decision support in medical emergency management for mass gatherings

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ABSTRACT

Conducting a safe and successful major event highly depends on the effective provision of medical emergency services that are often offered by different public and private agencies. Poor communication and coordination between these agencies and teams can result in delays in decision-making and duplication of efforts. Another related issue is that emergency decisions are usually made based on individual experience and domain knowledge of relevant managerial personnel. For sustainable knowledge management and more intelligent decision support it is beneficial to collect, consolidate, store and share these experiences in a form of a knowledge base or domain ontology. State-of-the-art surveys identify this gap that there is no common ontology describing the domain knowledge for planning and managing medical services in mass gatherings. Part of the reason is that the process of construction of such an ontology is not a trivial task. In this paper, we describe the process of developing and evaluating a Domain Ontology for Mass Gatherings (DO4MG) with a focus on medical emergency management. As part of the evaluation, we illustrate the application of DO4MG for implementing a case-based reasoning decision support for emergency medical management in mass gatherings. Such an implementation demonstrates the potential of using ontology for resolving terminology inconsistencies and their usefulness for supporting communication between medical emergency personnel in mass gatherings. We also illustrate how this ontology can be applied to different stages of medical emergency management as part of a system architecture. The lessons learnt from building DO4MG for this domain could be beneficial in general to the theory and practice of intelligent decision support and knowledge management in complex problem domains.

1. Introduction

Medical emergency decision making could be a challenging task, particularly during mass gathering events [2,75]. In mass gatherings, when a crisis occurs, medical emergency decisions are usually made under time pressure [3]. Further, these events typically involve participation of various emergency medical agencies that frequently use different terminology to represent the same concepts. This inconsistency can complicate communication between different emergency teams as well as integration and management of data recorded in these events.

Intelligent decision support systems aim to provide decision makers with timely, useful and valid information based on some pre-coded domain knowledge [12]; and medical emergency services (MES) in mass gatherings can benefit from access to such systems [27,74,75]. The underlying condition for successful development of such a system is creation of a reliable mechanism for collection, representation, and storage of domain knowledge. Literature shows that there is no common ontology describing the domain knowledge for planning and managing medical services in mass gatherings.

We suggest that better knowledge management for decision support can benefit from standardization of mass gathering's medical emergency management (MEM) terminology using domain ontology [64]. The importance of incorporating an ontology into a system architecture has been well recognized, in the context of intelligent decision support, as the means of knowledge representation and management and to assist decision makers with complex problem-solving [15,20,36]. With regard to mass gatherings, ontologies can improve coordination and interaction between different emergency agencies and facilitate data capture, storage, integration and querying of recorded data in the events. Moreover, the use of a common and unified domain ontology can improve the decision making process where most of the emergency decisions are dependent on individual experiences and domain knowledge of relevant managerial personnel.

The need for further research in knowledge management and decision support in medical emergency management is well recognized

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[2,27,71]. A domain ontology for medical emergency management is a mechanism for providing a consistent view on the problem domain that can be used by all concerned stakeholders. Delir Haghighi et al. [18] introduced a domain ontology, named DO4MG (Domain Ontology for Mass Gatherings), and discussed how it could improve decision making in the field of medical emergency management by providing a unified and common knowledge base for intelligent decision support. However, one of the major requirements to adopt a domain-specific ontology is to determine its fitness and suitability over other existing ontologies in the same field and to evaluate the given ontology against certain criteria and a set of standards [10,70]. Ontology evaluation requires the use of explicit and formal criteria that match ontology construction objectives.

During the years, many evaluation approaches and criteria have been proposed to analyze and validate ontologies [10]. These evaluation methods normally focused on specific domain problems, and were tested for validating a certain type of ontology. These past studies confirmed that it is important to select an evaluation approach which fits the given ontology and its application domain. In this paper we present an approach for creating and evaluating the domain ontology for medical emergency management. We undertake the task of an extensive review of the existing approaches for ontology evaluation and propose a systematic process suitable for the mass gathering ontology. This includes assessment of the proposed ontology by domain experts and from its application perspective. We describe the application of the ontology within the overall mass gathering management as an integral part of knowledge management for running a safe event [19]. An example of a case-based reasoning (CBR) intelligent decision support implementation of this architecture is also presented.

In this paper, we make two main contributions as follows.

- First, we present a thorough review of current ontology evaluation methods on the basis of multiple criteria and describe the process of selecting the ones applicable for validation of DO4MG. These include the process of empirical testing of the evaluation method with the domain experts. In doing so, we also report on the lessons learned and therefore provide a refined understanding of ontology evaluation methods.
- Second we describe an ontology-based system architecture for medical emergency management in mass gatherings that incorporates the DO4MG ontology, which illustrates effectiveness of the proposed approach for ontology construction and evaluation. As an example, a CBR prototype decision support system (DSS), which can be used during the pre-event and post-event stages of mass gathering events for respectively training, workload estimation and data collection and integration is described. This DSS uses the ontology to provide a unified and standard vocabulary of the domain and to overcome any problems that can arise from inconsistencies in terminology and discrepancies of data collection in emergency management for mass gatherings.

Both contributions, although validated in a specific problem domain, can provide a useful insight for researchers and practitioners in dealing with complex decision situations, which involve multiple agencies and a wealth of expert knowledge.

The rest of this paper is organized as follows. Section 2 defines ontologies and presents the benefits of ontologies for intelligent decision support systems. Section 3 provides an overview of decision support systems for MEM in general and then discusses the application of ontologies to medical management emergency in mass gatherings. Section 4 describes the development process that we propose for building DO4MG including pre-development and design stages. Section 5 presents an overview of the current ontology evaluation approaches and provides justification for selected evaluation methods for DO4MG. Section 6 describes the application of the evaluation and refinement methods for verifying the contents and testing usability of DO4MG. These include criteria-based and application-based evaluations. The criteria-based evaluation includes the refinement of DO4MG according to the domain experts' feedback. The application-specific evaluation of DO4MG details the overall architecture for intelligent decision support in mass gatherings and an illustration of the case-based reasoning prototype developed to test its usability. Finally, Section 7 concludes the paper and suggests some directions for further research.

2. The role of ontologies in DSS

An ontology presents 'a shared and common understanding of the knowledge domain' [15:786] using major concepts and terms applied in that domain and identifies the relationships between these concepts. Ontologies enable aggregation and use of knowledge items and sub-processes and provide a way to move from a document-oriented view of knowledge management to a content-oriented view [63]. An ontology provides a world view and the shared understanding of a given domain which can be used as a unifying framework to address the domain problems [66]. As Gruber suggests "an ontology is an explicit specification of a conceptualization" [29:1].

The core of any decision support system is knowledge from which, and of which, decisions are made [12]. To provide a structured and formal representation of knowledge, ontologies have been applied to a number of DSS [15,48,51]. For example, Musen et al., [51] proposed EON architecture as a decision support system for protocol-based therapy. EON integrates an ontology that represents clinical protocols such as drug therapy to benefit from a shared and computer-based representation of all the common data elements in a precise and consistent structure. EUEDE (End-User Enabled Design Environment) [48] for dairy farm management applied semantic ontology tools to achieve effective decision systems, which are context sensitive to end-user factors and provided a generic knowledge model applicable across rural industries.

OntoWEDSS (Ontology-based Wastewater Environmental Decision-Support System) [15] uses ontologies to solve complex problems related to environmental science and engineering. The inclusion of ontologies in that study allowed improved modeling of wastewater treatment processes and facilitated the communication among different components of the environmental DSS. The advisory system for crime investigation processes proposed by Dzemydiene and Kazemikaitiene [20], used ontologies to ensure that the crime information was extracted and represented in a structured model format appropriate for decision-making in crime investigation.

Most of these examples do not report on the ontology evaluation process, neither provide enough details on general principles that can be applied to developing and evaluating other ontologies. At the same time prior research conducted by Sujanto, et al. [64] for example, demonstrated the importance of a rigorous process of ontology development and the lack of consistency in current approaches to ontology evaluation. Sujanto et al. [65] proposed a framework for development and evaluation of medical emergency management ontology from the generic design science principles.

In the work presented in this paper, we focus on qualitatively extending the approach introduced by Sujanto et al. [64] for medical decision support in the mass gathering context. We also propose a systematic validation methodology which includes formal methods and uses expert feedback for validation and refinement of the ontology for decision support.

The next section introduces the context for our research and discusses the importance of intelligent decision support in medical emergency decision making.

3. Intelligent decision support for medical emergency management

Decision support systems are in high demand when users need to make informed decisions especially during emergency situations [12,74]. Emergency situations are time-constrained and dynamic