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Knowledge-centered design of decision support systems for emergency management

Daniela Fogli *, Giovanni Guida

Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Brescia Via Branze 38, 25123 Brescia, Italy

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ABSTRACT

This paper focuses on the design of decision support systems for emergency managers in charge of planning, coordinating and controlling the actions carried out to respond to a critical situation. A novel knowledge-centered design methodology is proposed and demonstrated through the application in a concrete case study in the field of pandemic flu emergency management. Knowledge-centered design is based on a rational and structured approach to the elicitation and modeling of the knowledge concerning the target environment, the application domain, the intended users, their tasks, and the specific activities that the decision support system is expected to provide. Our proposal aims at overcoming some of the limitations of user-centered and activity-centered design in the specific context of decision support systems. Knowledge-centered design is based on an iterative process that goes through four main phases, namely: target environment identification, domain understanding, user characterization, and functional analysis. The paper illustrates each phase in detail and discusses the application in the proposed case study.

1. Introduction

Emergency management encompasses a variety of activities, such as training and preparation, early signal detection, planning, mitigation, response, and recovery, which are usually carried out to cope with potentially catastrophic events caused by natural hazards or human behavior [18]. Indeed, an emergency may have a huge impact on every business, service provider, community and family in a nation, not just because of illness and loss of life, but also for the negative effects it exerts on workforce, availability of goods and services, and economic and social conditions in general. A structured and coordinated management is fundamental to be prepared and to minimize the consequences that an emergency may originate. Different approaches to emergency management can be found in current literature. They can be roughly divided in three classes: i) solutions based on social media [8,21,39], which aim at improving information exchange and sharing, and to favor citizens' participation; ii) emergency management information systems [2,9,42], designed to address the problem of enabling communication and coordination among independent institutions that may have different and competitive goals, and where a central control is absent; and iii) decision support systems [6,15,45], proposed to provide emergency managers with indications for selecting among alternative courses of actions in complex and uncertain situations.

By examining closer the third class of approaches, we can observe that *Decision Support Systems* (*DSS*) are usually applied in specific emergency situations – for example nuclear and radiological emergencies [34], earthquakes [12], health emergencies [20] – or to address specific aspects of emergency management, such as situation awareness [35], improvisation [24], and context awareness [25]. The principles on which the design of these systems is based are mostly domain-dependent; only rarely general and systematic approaches to the design and development of DSSs are proposed in literature. Among the few examples, we mention the knowledge-based framework proposed in [10], which exploits semantic web technologies to model the application domain and fuzzy cognitive maps to represent emergency plans; Ahmed et al. [3] present a scenario-driven, process-oriented DSS generator; finally, the work described in [25], even though focused on context-awareness, proposes a high-level design theory for real-time accident handling.

All such systems and approaches, even though representing important success cases, offer only a limited contribution to the general topic of DSS design for emergency management. Most of the works mentioned above focus on the conceptual and technical aspects of the DSS, but leave the design methodology and the relevant design processes in the background. Moreover, each system seems to adhere to a specific design practice, which can hardly be replicated in different contexts. The first goal of our work is, therefore, to face the issue of generality and to propose a methodology to DSS design that can fit the needs of a variety of application contexts and can be effectively applied in practical cases.

Going deeper into the design issue, the paradigm of *user-centered design* is advocated in recent literature about emergency management as one of the most sound and viable approaches to DSS design (see, for instance, [5,7,29]). User-centered design requires to involve users throughout the design process, from requirement and task analysis to usability testing; in this way, users can directly influence how the system takes shape [1,28]. Recently, however, Donald Norman has

* Corresponding author. Tel.: +39 030 3715666; fax: +39 030 380014.
E-mail addresses: fogli@ing.unibs.it (D. Fogli), guida@ing.unibs.it (G. Guida).

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warned that satisfying user requests should not be overestimated: "listening to customers is always wise, but acceding to their requests can lead to overly complex designs" [27]. Users do not necessarily know what is good for them. Moreover, different users may express different requirements, and thus satisfying the needs of a user may imply to neglect those of another. User-centered design, although important, might not be enough and in some cases might even turn out to be harmful. Therefore, Norman suggests that *activity-centered design* is superior to the mere user-centered approach and should be preferred in most cases [27]. Indeed, while user-centered design focuses on what a user considers good for him/her, activity-centered design advocates the need to take into account what is actually good for a user performing a given activity. The difference between these two standpoints is evident: while the former is more subjective and puts the design responsibility onto the user's shoulders, the latter is more objective and restores the designer in his/her original role.

A closer analysis of these approaches reveals, however, that users – with their needs and activities – are generally not the ultimate targets of a DSS. Both the user and the system are part of a larger environment – a process, an organization, a social context – that is expected to benefit from the availability of the DSS. Considering the case of emergency management, while it is important to consider the needs and preferences of emergency managers and the requirements emerging from the analysis of their activity, it is equally – or even more – important to take into account the actual needs of the population affected by the emergency and the goals of the institutions in charge of facing the emergency. Both user-centered and activity-centered design paradigms hardly take into account these aspects and might reveal weak in complex decision making situations.

The second goal of our work is, therefore, to propose a novel approach to DSS design that focuses not only on the users and their activity, but also on the knowledge about the environment where the users operate and the DSS will be employed. Our standpoint is that if the users can express their needs and preferences, and the analysis of their activity can reveal much of the actual tasks they are in charge of, only the consideration of a larger environment can allow identifying the real goals, constraints, processes, and rules of the decision making activity. We call this novel approach *knowledge-centered design*, since it puts knowledge in the center: knowledge about the users of the DSS, the activities they are supposed to carry out with the support of the DSS, and the environment where the DSS will be applied. Knowledge-centered design is based on an evolutionary concept, where a design can grow step by step towards a better design, through an incremental process of mutual adaptation where each involved party – the user, the system, and the environment – can impose something to the others and accept or reject the impositions received. Our knowledge-centered design methodology does not aim at substituting user- or activity-centered design, but incorporates these concepts in a wider framework, thus making the whole design process more sound and robust. Moreover, it strongly promotes a participatory approach to design [36], where different subjects – managers, process and organization specialists, domain experts, and operative personnel – are involved in the design process and bring their specific knowledge and experience.

The paper is organized as follows: Section 2 presents an overview of the knowledge-centered design methodology; Section 3 introduces the HEALTHREATS case study; Sections 4 to 7 focus on the individual phases of the methodology and present them in detail with reference to the case study considered; Section 8 illustrates the main features of the implemented DSS prototype, and Section 9 reports the main outcomes of DSS evaluation; and finally, Section 10 discusses the results obtained and outlines some issues for future research.

2. Knowledge-centered design: the methodology at a glance

2.1. The phases

The core of knowledge-centered design is the consideration of the different kinds of knowledge that are involved in the design of a DSS, namely: (i) knowledge about the target environment where the DSS will be used, (ii) knowledge about the user tasks, and (iii) knowledge about user profiles and interaction patterns. In order to satisfy this need in a structured and effective way, a *knowledge-centered design methodology* grounded on four main phases has been defined, as illustrated below (see Fig. 1):

1. *Target environment identification*. This phase has the goal of developing a deep understanding of the piece of real world where the DSS will be applied, including all the stakeholders that will be influenced, directly or indirectly, by the system, their work practices, the tools they are used to interact with, as well as the social and physical contexts in which they operate.
2. *Domain understanding*. Domain understanding aims at identifying, collecting and representing all the knowledge relevant to the specific domain of the DSS, including the basic entities and processes

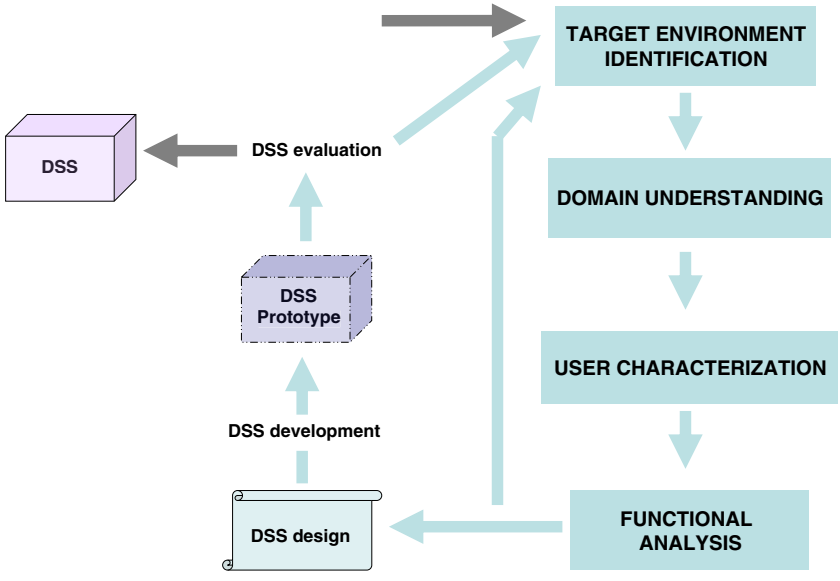

Fig. 1. The knowledge-centered design methodology.