Identifying and confirming information and system quality requirements for multi-agency disaster management

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ABSTRACT

This paper investigates the relevance and assurance of information and system quality as requirements for information systems success during disaster management. Despite the many examples of poor information quality and poor system quality, research on the relevance and assurance of these requirements is sparse. In order to design successful information systems for disaster management, a context related understanding of the organizational and technical measures for achieving these requirements is necessary. Accordingly, the goal of this paper is to identify and confirm information and system quality requirements for the design of information systems for disaster management. The results of our interviews with information architects indicate that while information quality requirements are considered to be very relevant, these are hard to measure and assure, and that currently much effort is being put into improving system quality requirements such as interoperability and ease of use.

Keywords

Information quality, system quality, information systems, disaster management

INTRODUCTION

Responding to a disaster, either natural (e.g., floods, earthquakes) or human induced (e.g., terrorist attacks) is a complex process (Bigley & Roberts, 2001) in terms of the number of actors, information systems and the interactions between actors and information systems. During the response phase, multiple autonomous agencies form a response network and need to share information at strategic, tactical and operational echelons. As a disaster evolves, the state and configuration of multiple elements in the response network changes rapidly, indicating a high level of dynamics in information demand and supply. The process of information sharing and coordination is further hampered by time pressure (Smith & Hayne, 1997), event uncertainty (Argote, 1982) and information need unpredictability (Longstaff, 2005). The physical distance between the tactical and strategic echelons, as well as the differing time spans for decisions, poses additional challenges for designing systems for information sharing and coordination. In other words, complexity, dynamics and uncertainty are contingency factors influencing information sharing and coordination in the multi agency response network.

Under such contingencies sharing and dissemination of information is both critical and problematic (Manoj & Baker, 2007) and poor information quality (IQ) can be disastrous for both relief workers and victims (Fisher & Kingma, 2001). Examples for poor IQ are incorrect, outdated or inconsistent information. For relief workers, high IQ is critical, because their activities are information intensive (De Bruijn, 2006) and their effectiveness largely depends on the information they have available (Davenport & Prusak, 1998). Alongside IQ, system quality (SQ) is another key element for effective disaster management. While IQ is used to describe the characteristics of the information produced or transferred by an information system, SQ refers to the characteristics of the information system itself (e.g., Delone & McLean, 1992; Nelson, Todd, & Wixom, 2005). In this paper we take a socio-technical perspective on systems, including both human and technical components (Bostrom & Heinen, 1977a). Examples of SQ requirements include the interoperability, response time and the flexibility of the information system used. We elaborate on these requirements later on in this paper.

Previous research on IQ (e.g., Miller, 1996) and SQ (e.g., Nelson, et al., 2005) identified a wide range of requirements in business environments (over 30 IQ and 11 SQ requirements). However, little is known about the meaning of these requirements in the context of disaster management. In contrast to relatively predicable business environments, information and communications needs for disaster management are highly diverse in nature, reflecting the multiple purposes for information and communication and the different activities and information and communications requirements that occur at different times and locations with respect to a disaster (National Research Council, 2007). Moreover, the multi-actor environment of a disaster does not only create varying IQ and SQ descriptions, but also raises the questions on how these dimensions can be assured in a temporary, fragmented and ad-hoc environment. Hence, the main research question of this paper is twofold: *what are critical information and system quality requirements for multi-agency disaster management and how do information architects deal with these requirements in practice?* Accordingly, the objective of this paper is to identify key IQ and SQ requirements for multi-agency disaster management and describe how these are assured in practice.

This paper proceeds with a discussion on the research approach followed to achieve the objective of this paper. Next, we discuss and catalogue IQ and SQ from a theoretical perspective. Following the theoretical discussion, the list of requirement is shortened by selecting requirements that were reported to be insufficient during disaster management efforts. The resulting shortlist of IQ and SQ requirements was verified via a round of expert-interviews. This paper concludes with a discussion on how the relevant IQ and SQ requirements are perceived and practice and some suggestions for further research.

RESEARCH APPROACH

The research approach we followed builds upon three research instruments: (1) literature review, (2) empirical case studies and (3) semi structured interviews. The research approach is visualized in the following table.

Research instruments / Concepts	I. Literature review	II. Empirical Case surveys	III. Exploratory and confirmatory interviews
Information Quality	Generic/context independent requirements	Disaster management specific IQ requirements	Confirmed disaster management specific IQ requirements and measures
System Quality	Generic/context independent requirements	Disaster management specific SQ requirements	Confirmed disaster management specific SQ requirements and measures

Table 1: Research approach

First literature on IQ and SQ was reviewed. We used Scopus to survey electronic databases in 2008. The key terms used were 'information quality' and 'system quality'. The goal of the literature review is to identify IQ and SQ requirements mentioned in literature. The literature review resulted in a general list of IQ and SQ requirements which helped us to gain understanding of the range of requirements. This list is presented in the next section. Next, we used the case survey approach to find IQ and SQ problems reported specifically in disaster management cases. Yin and Heald (1975) argue that case surveys are particularly suited when a heterogeneous collection of case studies exists and researchers are interested in their characteristics rather than the authors' conclusions. The approach combines advantages of survey research and qualitative case studies, as it allows to capitalize on the richness of case material while using quantitative analyses (Larsson, 1993). We used qualitative content analysis with human coding as a tool. The coding process was guided by a coding protocol (this is available upon request). In order to gain a rich illustration of the dynamics at hand and to develop and refine the coding protocol, we first applied to coding protocol for the qualitative analysis on two initial cases. Then, we used the IQ and SQ requirements as keywords to survey problems in the case studies. Four empirical cases were studied: 1) the 9/11 attacks, 2) hurricane Katrina, 3) the 2005 Asian Tsunami and 4) the large fire at the Schiphol Detention Complex in the Netherlands. These cases were selected based on two key criteria. The first criterion is that these cases are well documented and evaluated by research committees. This criterion allows us to find as much IQ and SQ problems as possible. The second criterion is that these cases are complementary in terms of disaster source (i.e., terrorist attacks vs. natural disaster). Finally, the IQ and SQ requirements identified from the case surveys were used to develop an interview protocol (this is available upon request). This interview protocol was used to systematically conduct semi-structured interviews with senior information architects. The interview protocol was pre-tested with information architects in a different safety region of the Netherlands. The sampling of the respondents is discussed in the interviews section of this paper.

THEORETICAL BACKGROUND

Previous work on designing information systems for disaster management

There exists a sparse but slowly expanding body of literature on designing information systems for disaster management. For instance, Meissner et al (2002) sketched requirements and innovative technology for an integrated disaster management communication and information system, addressing in particular network, configuration, scheduling and data management issues during the response and recovery phases. Later, Turoff et al (2004) have published a set of general and supporting design principles and specifications for a dynamic emergency response management information system (DERMIS) by identifying design premises resulting from the use of the emergency management information system and reference index. Taking a supply chain perspective, Chen et al (2008) have discussed the need for a comprehensive set of data standards (semantics and internal structures) for emergency management to better address the challenges of information interoperability. Building on the existing body of knowledge, we still lack a systematic categorization of requirements for designing information systems in the disaster management domain. For this purpose, we use the information systems success model discussed in the next section.

An Information systems success perspective

Delone and Mclean (1992) were the first to develop a causal model for studying the success of information systems. The original model contains six concepts which are illustrated in figure 1.

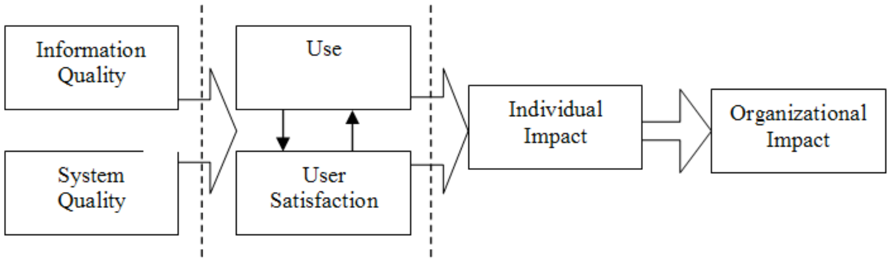

Figure 1: Information systems success model (Delone & McLean, 1992)

This model has been applied and tested numerous times and in various domains. However, to our knowledge, this model has been only sparsely applied in the domain of disaster management (e.g., Fisher & Kingma, 2001) For the purpose of this research, we limit our scope to investigating two antecedents of information systems success: information quality and system quality. These antecedents are discussed next.

Information quality

Throughout literature, we found that the concept of quality has been defined varyingly depending on the context of use. For instance, quality has been defined as conformance to product specifications (Levitt, 1972), fitness for use (Juran, Gryna, & Bingham, 1974) and meeting and/or exceeding customers' expectation (Gronroos, 1983). Accordingly, multiple quality frameworks and requirements are proposed by the different scholars. Usually, the quality concept is specified by a proverb such as: product, process, service, information and system. For the purpose of this research we are particularly interested in quality of information and of the information systems used. This demarcation suggests focusing on information system literature. However, even in information systems literature, quality itself is relatively "ill-defined" (Nelson et al. 2005).

Information quality (IQ) is not a new concept in information systems research. IQ is a pervasive social concept and a key antecedent of information systems success (Delone & McLean, 1992). What is new in the past several decades is the explosion in the quantity of information and the increasing reliance of most segments of society on that information (Ballou, Madnick, & Wang, 2004). Accordingly, IQ has been studied by multiple scholars (e.g., Ballou & Tayi-Kumar, 1999; Miller, 1996; Strong, Lee, & Wang, 1997). As a result multiple frameworks are proposed for capturing IQ requirements (e.g., English, 1999; Redman, 1995; Wang & Strong, 1996), each viewing and treating this concept differently. Usually, scholars do not define what IQ is, instead they prefer to provide a set of requirements (or dimensions) quality information should meet. These requirements can bee used as benchmark to improve the effectiveness of information systems and to develop information quality strategies (Miller, 1996). The number of requirements proposed by scholars is very different, for instance Pipino, Lee & Wang (2002) suggest information quality has sixteen requirements, while Miller (1996) suggest there are ten requirements. A more comprehensive overview of IQ requirements is provided by Lee et al (2002) who suggest the categorization of twenty-one requirements in four categories. These categories and requirements are listed in table 2.

Category	Requirements	Category	Requirements
Intrinsic	Accuracy	**Representational**	Interpretability
	Objectivity		Concise representation
	Correctness		Consistent representation
	Believability		Understandability
	Reputation		Format
Contextual	Relevancy		Compatibility
	Value added		Ease of Operation
	Timeliness	**Access and access security**	Accessibility
	Coherence		Access Security
	Appropriate amount of data		
	Completeness		
	Validity		

Table 2: Information quality categories and requirements (Based on Lee et al, 2002)

Even though table 2 shows a comprehensive list of IQ requirements, not all of these requirements are relevant for multi-agency disaster management and some of these are even correlated (Lee, et al., 2002). For instance the ease of operation depends on the format, amount of information and understandability. On the other hand, some of these requirements are even considered to be properties of the information system, for instance accessibility and access security (Nelson, et al., 2005). Hence, we need a more in-depth understanding of the context in order to define key requirements. For this purpose we surveyed four cases which we discuss after elaborating the second concept in this paper, the system quality.

System Quality

System quality (SQ) is a concept used to evaluate multiple dimensions of the information processing system required to produce the output (Delone & McLean, 1992). Overall, SQ has received less formal and coherent treatment than IQ in the IS literature. Traditionally, SQ requirements are related to be technical engineering requirements such as reliability and availability. As technical systems became more tightly coupled, requirements such as flexibility and interoperability were also considered to determine the SQ. While most of such requirements were individually studied in detail, there are relatively view studies which threat these requirements as a related and coherent set of system quality characteristics. In the late 90ths when systems were considered to be carriers for services, SQ requirements were often closely related to service quality and ease of use (Nelson, et al., 2005). These interrelationships make it all the more important to ensure conceptual clarity in the specification and distinction of constructs. The focus is on the characteristics of the information system itself rather than on the characteristics of its product (Delone & McLean, 1992). The requirements of system quality represent user perceptions of interaction with the system over time. Delone and McLean (1992) have identified multiple variables for system quality, including system flexibility, accessibility, ease of use, integration, efficiency and response time. We use these requirements as search terms to survey case study reports on disaster management efforts. In the next section we discuss the IQ and SQ problems resulting from the case surveys.

CASE SURVEYS

Information quality problems during disaster management

The main objective of our case survey was to identify and describe IQ and SQ related problems which occurred during the response the disasters. Using the problems found, we aim to shortlist the number of IQ and SQ requirements for designing information systems specifically for disaster management. Table 3 lists the IQ dimensions and related problems pointed out in evaluation reports on the four empirical cases.

IQ requirement	Description of IQ problems in case studies
Relevance	"Relevant information, that is information suited to its intended use, was needed to support emergency and recovery operations of all kinds" (Dawes, Creswell, & Cahan, 2004).
Quantity (amount of information)	When a large-scale disaster happens, a great deal of information occurs in a short period of time (Atoji, Koiso, & Nishida, 2000), resulting in too much information to process (Jenvald, Morin, & Kincaid, 2001) and straining the capacity of the emergency management and communication systems.
Accuracy	In emergency management, information about technical conditions may be ambiguous and unreliable (Kontogiannis, 1996). Furthermore, the emergency starts out with a lack of information, which then turns into large amounts of imprecise information (Manoj & Baker, 2007).
Timeliness	"Sending us very stale sit rep info that has already been updated (earlier) is not as helpful. Is there a way to coordinate the info flow so we don't waste time receiving such old data and you folks don't waste time sending us stuff?" (Christopher & Robert, 2006).
Completeness	In the response to the 2004 Tsunami, "mostly, the information is incomplete, yet conclusions must be drawn immediately"(Samarajiva, 2005). "During Katrina, the federal government lacked the timely, accurate, and relevant ground-truth information necessary to evaluate which critical infrastructures were damaged, inoperative, or both"(Townsend et al, 2006).
Format	To enable information sharing, document type definitions have to be in a well-defined format (Jenvald, et al., 2001). During the response to 9/11, sometimes valuable information necessary for re-establishing normal operations in non-emergency organizations had been kept only on paper, such as legal files for cases in the process of litigation. This information was either destroyed or made inaccessible due to the closure of buildings that needed thorough inspection or repair before they could be re-occupied (Dawes, et al., 2004).
Consistency	If several information systems suggest different location coordinates, this inconsistency delays decision making (Fisher & Kingma, 2001). Firefighters rushing to the Shiphol Detention Complex received inconsistent information about the available gates to the area and were delayed in finding the right gate (Van Vollehoven et al, 2006).
Availability	During the response to Katrina, the absence of a central system to manage and promptly respond to inquires about affected foreign nationals led to confusion. Information search was seriously limited, resulting in a severe lack of information as a basis for decision making in this urgent, uncertain, swiftly moving context (Comfort & Kapucu, 2006). In response to the 2004 tsunami, many response agencies stationed further of the coast lacked information warning them about the floods and hazards (Samarajiva, 2005).

Table 3. Description of IQ problems specifically pertaining to disaster management

Table 4 list IQ problems we found in case study reports and give impressions of the context for IQ requirements. The case surveys resulted in less IQ requirements that the general literature review on IQ. As discussed in the research approach section, we evaluate the importance of the IQ requirements in table 4 using semi-structured interviews with information architects. We discuss the results after presenting the SQ problems pointed out by the case surveys.

System quality problems during disaster management

In the context of disaster management, both the information demand and supply keep changing over time, making flexibility and integration particularly important requirements for decision-support applications. Systems that integrate data from diverse sources can improve organizational decision making, and flexibility allows decision makers to easily modify applications as their information needs change (Gray and Watson 1998; Sakaguchi and Frolick 1997). The following table list some system quality related problems during interagency disaster management pointed out in some reviewed literature.

SQ requirement	Description of SQ problem in case studies
Accessibility	The 9/11 case shows that access to data across agency lines also needs to be improved to support interagency coordination (Comfort & Kapucu, 2006). "In some cases, needed information existed but was not accessible" (Dawes, et al., 2004).
Response time	If there was a comprehensive plan to quickly communicate critical information to

	the emergency responders and area residents who needed it, the mixed messages from Federal, State, and local officials on the re-entry into New Orleans could have been avoided (Townsend et al, 2006).
Reliability	"…responding to disaster situations, where every second counts, requires reliable, dedicated equipment. Public safety officials cannot depend on commercial systems that can be overloaded and unavailable; experience has shown that these systems are often the most unreliable during critical incidents when public demand overwhelms the systems" (National Research Council, 2007).
Flexibility	"A catastrophic incident has unique dimensions/ characteristics requiring that response plans/strategies be flexible enough to effectively address emerging needs and requirements"(National Research Council, 2007). "The lack of such capacity at the regional level that includes municipalities, counties and special districts, as well as nonprofit and private institutions that serve a metropolitan region, was evident in the effort to mobilize response to the 9/11 events" (Comfort & Kapucu, 2006).
Integration (inter-operability)	. "…given the number of organizations that must come together to cope with a major disaster, the interoperability of communications and other IT systems is often cited as a major concern" (National Research Council, 2007). The need for integration intensifies as the number of organizations engaged in response operations increases and the range of problems they confront widens (Comfort & Kapucu, 2006).

Table 4: Description of SQ problems specifically related to disaster management

Table 5 provides an overview of SQ problems in the context of disaster management. Together with the requirements mentioned in table 4, the importance of these requirements and the approaches for dealing with them are tested using semi-structured interviews with senior information architects. We discuss the findings in the next section.

INTERVIEWS

Respondent sampling

The objective of the semi-structured interviews we conducted was twofold: first to test if the disaster specific IQ and SQ requirements identified matched the requirements information architects in practice are struggling with and, secondly, to find out which measures information architects use or plan to use for dealing with these requirements.

According to these objectives, the sampling of the respondents was selective. Schatzman & Strauss (1973) suggest that after several observation visits to the sites, the researcher will know who to sample for the purpose of the study. Previous observations (Bharosa, Appelman, & de Bruijn, 2007; Bharosa, Lee, & Janssen, 2009) contributed to the consolidation of impressions or confirmed information based on documentary evidence or in the interviews. Based on previous observations on multi agency disaster management exercises in Rotterdam we selected fifteen information architects for our interview. Information architects are the people most likely to be affiliated with IQ and SQ requirements. Three main criteria guided the selection:

1. the respondents needed to have at least five years experience with multi agency disaster management.
2. they must occupy a senior position in either the development or use of information systems for multi agency disaster management in Rotterdam safety region.
3. taken together the sample represents the main relief agencies in and government departments in the Netherlands that are likely to be involved during a major disaster. The list of respondents and their agencies are presented in the appendix.

Method

The personal interviews were conducted in the second semester of 2008. Each respondent was interviewed in person at their office for approximately one and a half hour. Prior to the interviews, a summary of this research and the type of questions for the interview was emailed to each of the respondents, thus ensuring that all interviews followed the same general format and that interviewees could provide more informative data. Each interview was guided by a predefined and pre-tested interview protocol containing open ended and closed questions (this is available upon request). The interviews were voice recorded on tape so as to minimize data loss due to note-taking. The interviewer attempted to focus the discussion on IQ and SQ requirements and measures. Shortly after each interview, the interview notes were first transcribed in MS Word and emailed to the respondents that were requested to validate these within two weeks. Validation means here that respondents checked the transcripts of the interviews on inconsistencies and judged whether or not the transcripts were a truthful account of the interview.

Analysis

A qualitative approach to data analysis was adopted in the study. Researchers have suggested that, when using a qualitative approach, a set of initial seed categories may be generated to guide the research (Miles & Huberman, 1994). The seeds and related questions used for the interviews are presented in the appendix. To be able to compare the results of the various interviews, the text analysis application ATLAS.ti is used. ATLAS.ti can be classified as a qualitative text analysis application (Klein, 1997), which fits the results of the conducted semi-structured interviews with the in-the-field experts. Another main reason for using this tool is the ability to generate network views (see figure 1). Within these network views different codes and their mutual relationships can be visualised, which provide a general overviews of relationships between they key concepts of the interview.

Results

The interviews reveal how various information architects from different agencies have different opinions and knowledge on several IQ and SQ requirements and measures. Almost all the respondents underline that the information systems used for disaster management are designed, developed and operated in a very fragmented and heterogeneous way, making it hard to cope with IQ and SQ problems. The reason given for this is that in the Netherlands, each of the relief agencies has their own information architects, who over the years have developed all kinds of information systems focused on satisfying organizational requirements rather than multi-agency IQ and SQ requirements. In addition, some information architects mention that many of the information systems used for multi-agency disaster management, were actually developed for mono-agency routine operations. When considering IQ and SQ requirements, most respondents agree on the lists given both in terms of relevance and completeness (note that this list consists of the dimensions elicited from the case studies). What they do not agree on is the type of measures (technical or organizational) for addressing these requirements. Measures advocated range from organizational (introduction of a boundary spanning information manager) to technical measures (development of a service oriented architecture). The following network view illustrates the importance of the various IQ requirements we discussed with them. Note that the numbers in the boxes indicate the amount of respondents confirming the requirements as challengers for their information architecture.

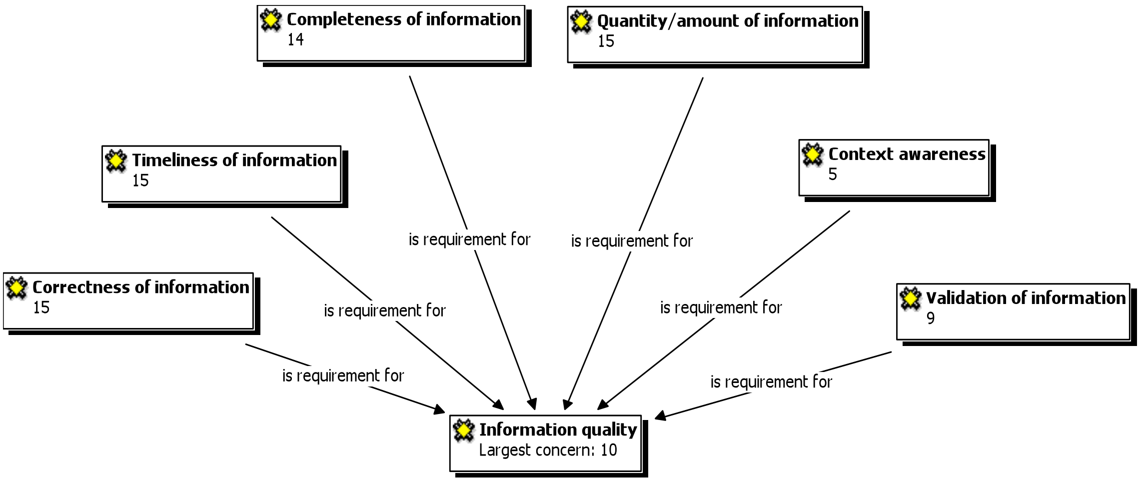

Figure 2: network view for the information quality requirements

Figure 1 shows the confirmed IQ requirements for the total number of respondents. Note that context awareness and validation of information are mentioned by respectively five and nine respondents as requirements for IQ. Ten of the fifteen respondents regarded IQ assurance as a larger concern than SQ assurance, while four of the fifteen regarded SQ assurance as largest concern. The most often mentioned reason that respondents give for this is that a system that has to process low quality information can not turn this information quality higher. Moreover, all the respondents said that IQ is relatively harder to measure than SQ. Hence, for them it remains difficult to improve what they cannot measure. Figure 2 illustrates the confirmed SQ requirements. Note that context awareness is also considered to be an SQ dimension by five respondents, who also consider it as an IQ requirement. In addition, all respondents mention that ease of use of information systems is a critical SQ requirement, as there is not much time for learning how to use systems during a disaster.

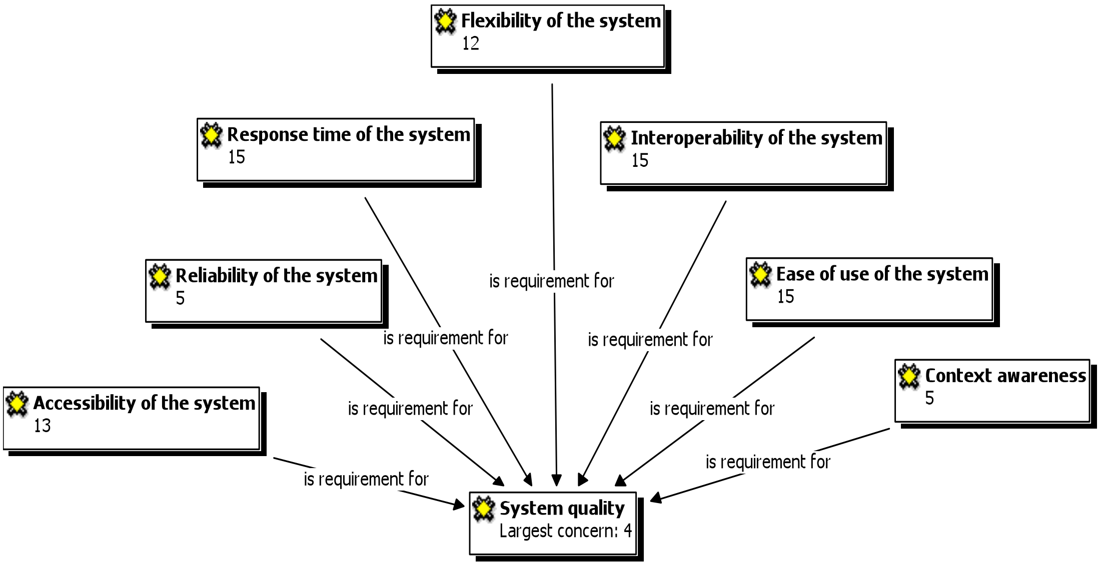

Figure 3: system quality requirements

A frequently mentioned addition to the dimensions of system quality is the 'robustness of the system', which in some discussion was considered to be related to 'reliability'. Overall, respondents consider larger problems in the organizational architecture than in the technical architecture. Technically, the mono-disciplinary system can be joined fairly easy, but there are many organizational problems among the different parties involved.

Both IQ and SQ were generally considered to be key challenges in the current information architectures. Network centric information sharing and Service Oriented Architectures were viewed as promising avenues that would ameliorate the quality of organizational and technical dimensions of future information architectures. However, not all experts are evenly 'enthusiastic' about increasing interoperability of various mono-disciplinary systems and in this way working toward network-centric organization. Their explanation for this is that despite the appealing advantages of these measures, the implications of the measures on the information architecture are not yet clear and need to be studied. For instance, network centric information sharing assumes a high level of uniformity and standardization on multiple levels of response such as in the military, whereas this is often not the case in the domain of multi-agency disaster response. Relief agencies are both autonomous and heterogeneous in their daily operations. This means that propositions of the network centric concept may require major changes in the organization structure (network instead of hierarchical), in the information architecture and the way individuals share and coordinate information.

One respondent mentioned that the different means and opportunities for information system usage for the strategic, management and operational echelon forms a major hurdle for ensuring high IQ and SQ for all echelons of response. This means that while the two higher echelons are generally stationed in well-equipped decision support rooms, first responders in the lower operational echelons are generally only supported by mobile phones and radio communication technology.

Another notable finding from the interviews is that achieving high IQ and SQ is problematic because the lack of standards in the disaster management domain. On the other hand, the respondents from the ministries and consultancy agencies say that they have proposed some standards dealing with IQ and SQ, but these standards are either neglected or slowly adopted because of existing regional or agency specific standards and legacy systems.

CONCLUSIONS AND DISCUSSION

The objective of this paper was to identify and confirm information quality (IQ) and system quality (SQ) requirements for disaster management. Hence, the question raised was: *what are critical information and system quality requirements for multi-agency disaster management and how do information architects deal with these requirements in practice?* In order to answer this question, three research activities were undertaken. The literature review suggest a wide range of SQ and IQ requirements some of which overlap and are not relevant for the context of disaster management. Using the list of requirements as search terms, the case surveys present a more refined and context appropriate list of IQ and SQ requirements. Finally, the interviews helped in pinpointing key IQ and SQ dimensions and ways of dealing with them. According to the interviewed information architects correctness, timeliness, completeness, amount and validation are key IQ requirements. On the other hand, the respondents argue that accessibility, flexibility, response time, interoperability and ease of use are the key SQ requirements. We also found that information architects do not agree on the type of measures, organizational or technical for fulfilling IQ and SQ requirements. Network centric operations and service oriented architectures were mentioned as future solution spaces.

Another key finding of the interviews is that even though the information architects consider IQ to be a larger concern than SQ, currently they put most of their effort into assuring SQ instead of IQ. The general feeling of the information architects is that assuring high IQ is difficult, if not impossible because of the complexity, dynamics and uncertainty of disaster management. Moreover, it is very hard for the system architects to measure IQ. Not being able to measure IQ reduces incentives for developing measures for dealing with IQ requirements. Further research needs to find ways to measure IQ and survey relief workers for key IQ problems, for instance during disaster management drills.

This study has two main limitations: (1) lack of a comparative analysis and evaluation of the IQ and SQ requirements and measures due to unavailability of field data, and (2) unavailability of the users of the information systems for interviews with the researcher. In order to complement the findings from the interviews, we have deployed surveys on IQ and SQ to relief workers who used information systems during disaster management drills in December 2008. We expect that the first findings from these surveys (n=112) can be presented during the ISCRAM conference.

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