# Netcentric Information Orchestration

## Assuring information and system quality in public safety networks



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Assuring information and system quality in public safety networks

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof.ir. K.C.A.M. Luyben;
voorzitter van het College voor Promoties
in het openbaar te verdedigen op maandag 24 januari 2011 om 15:00 uur
door

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For Dew,
my inspiration, my hero, my father...

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# Preface and acknowledgements

*"The PhD or Philosophiæ Doctor is the very highest accomplishment that can be sought by students. It signals that its recipient is now ready, eligible, indeed obligated, to make the most dramatic shift in roles: from student to teacher, from apprentice to master, from novice to independent scholar and leader".*

Walker et al., The Formation of Scholars (2008, p.10)

I read the above stated definition of what a PhD is during my holidays, just two months before my defense. This definition intrigued me because it specifies the roles that come with earning a PhD. Walker and colleagues add that "responsibilities associated with the degree include, knowing and doing, understanding and discovering, absorbing and creating, innovating and conserving, and become agents of change".

While I wish I had read their book, 'The Formation of Scholars', four years earlier, I am not sure whether I would have been able to understand what is meant by a "dramatic shift in roles" when I started my PhD research. Moreover, reading these roles and responsibilities in my job description could even have deterred me from ever starting with a PhD research. Yet, after 'four years of *knowing and doing, understanding and discovering, absorbing and creating, innovating and conserving',* I do belief that I have become a steward of my discipline and an agent of change. The reader will quickly discover what my discipline is and what kind of change I propose.

Nevertheless, growing into these roles and mastering the associated responsibilities was not an easy process. Writing this dissertation and conducting the research forced me to push out several boundaries. The past four years were like continuously conducting a SWOT (strengths, weaknesses, opportunities and threats) analysis on me. While analysis process sometimes led to short-term frustration, the long-term result is that I have become more self-aware and confident. I have come to accept my strengths and weaknesses and I know now how to deal with them. In additions, I have become aware of what motivates me and what discourages me, and I believe that increased level of confidence and self-awareness will bring me much comfort in future endeavors.

This dissertation is a collection of results gained from drawing on discussions and interactions between several others and myself. Accordingly, I would like to express my gratitude to these persons whom have contributed to this dissertation. First and foremost, I would like to thank Marijn Janssen, who acted as my coach before and during the project. Since this project started, Marijn worked hard in assuring that this project would continue regardless of the funding and positioning problems at our university. While Marijn was no expert on disaster management, after every meeting with him I felt as if I had just consulted some kind of 'Guru'. I will never forget the advice Marijn kept giving me whenever my work did not progress: "give it some hands and feet". In hindsight, this advice was the key to my progress, pushing me to think deeper about the implications of my thoughts.

Putting myself in Marijn's shoes, I suppose that this was not an easy task, especially since the primary initiator of this project, Prof.dr. René Wagenaar passed away at the beginning of this project. René, now I truly understand why you thought that this research was necessary, thank you for initiating it! I am very grateful to Prof.dr. Yao-Hua Tan for fulfilling the quintessential role of promotor and assuring that this project could reach the level that it did. Since Yao-Hua got involved in the final stage of this project, he did not have much opportunity to comment. Yet, the few comments he made were the ones that improved the quality of this dissertation. One could say that this is the trademark of a 'Chief Guru'.

As a member of the Faculty of Technology, Policy and Management, I had the privilege to correspond with some very intelligent people. 'Methodology-guru', Harry Bouwman for instance has supported me in assuring the rigor of my research. I will remember the lessons Harry! I have also spent many hours with 'Practice-guru' and 'Calvinist' Arre Zuurmond who has helped me in assuring the relevance of research. In the evaluation cycle of this research, I received valuable support from "Gaming-guru" Sebastiaan Meijer. The moment I had some doubts on my progress and capabilities, I could always consult Jolien Ubacht. In the hallway, I could always have a safety or security related discussion with Jan van den Berg. Whenever I needed some help, Jo-Ann and Eveline were always ready to listen and to help. I would also like to express my gratitude to colleagues Anne-Fleur, Bram, Ralph, Mark, Sietse, Janneke, Devender, Fatimeh, Andreas and Donna who have proofread this dissertation. Thanks everyone!

Thanks to Jaco Appelman, I was able to find the right contacts in the field of public safety networks. Jaco's analogy of mixing the police (blue team), fire department (red team) and medical services (white team) inspired me to choose the color purple for the cover of this dissertation. Without the support of contacts such as Wim de Rooij, Daan van Gent and Martijn Korpel, I would never be able to collect so much empirical data. Thanks for your support gentlemen!

I also had the privilege to work with some very smart students during this research project. Satiesh Bajnath, Dave Daas, Jalal Bani Hashemi, Victor den Bak and Bart van Zanten were not always easy to supervise students since they seemed to know more about a specific subject than I did. Therefore, it is only fair to say that I have also learned a lot from them. Even though some stories from other PhD students may suggest otherwise, I have managed to retain most of my friends and family during the 'four years of solitude'.

Good friends such as Vikash Mohan, Laurens Waling, Roy Dulam and Ashwien Bisessar have helped me to forget my work and enjoy 'the moment'. After the mental exhaustion from writing papers, Thijs Padmos and Bob Susser were always very happy to help me get physically exhausted from lifting heavy weights in the gym. Whenever I returned to Paramaribo, my friends Krisna Gajapersad, Donnovan Asmus, Dinesh Hardien and Henry Akodi enabled me to refuel for the Netherlands.

My parents Dew & Nanda have always encouraged and empowered my brothers, my sister and myself to study hard. My dad's saying "do your best in school if you do not want to wrestle with metal and grease like I do" has always fueled me to work hard. Dad and Mom, I am proud and grateful for everything you have done for me. Studying abroad was lonesome, seeing pictures of my siblings growing up so far away was difficult. I would like to thank my 'foster family' Mangre-Bharosa, whom have always helped me to relax and put things in perspec-

tive. I will never forget that my journey in the Netherlands started with their support. While I have kept missing my family and friends in Suriname, Ashok, Hilda, Navin & Ryan have always reduced the feeling of solitude.

Last, but certainly not the least, I would like to thank my life partner Shailiena Sardjoesingh. As witness to the countless nights and weekends of work that went into this dissertation, she still was always very kind, patient and supportive. Even though she had to work and study as well, I could always count on her for a warm meal and a cup of coffee. I know this process was hard on her especially when our weekend started to look like normal working days. Yet, she always found some way to keep me motivated. It was not always easy for her having somebody around the house who was still thinking about his work. Thanks for everything!

Nitesh Bharosa,
Delfgauw

# 1 Assuring information and system quality

*"Indeed, research is often guided by the desire to improve practice"*

-Andreas Faludi, Professor Spatial Policy Systems

## 1.1 Introduction

In 2005, an advisory committee to the Dutch Ministry of Internal Affairs and Kingdom Relations (ACIR, 2005) revealed two major problems in public safety networks: (1) having access to correct and complete information and (2) sharing information between the agencies. Three years later, the 'All Hands on Deck' workshop for government officials and relief agency commanders, concluded that information management in Public Safety Networks (PSNs) is still a major problem in the Netherlands (ASE, 2008). Today's PSNs do not only include the traditional relief agencies such as the fire brigade, police department and medical services, but also includes local municipalities, military, governmental departments, companies, infrastructure operators and citizens (Scholtens, 2007). The most recent investigation by the Dutch Inspection for Public Safety (IOOV, 2010) has yet again concluded that most PSNs still perform poorly when it comes to information management during multi-agency disaster response. This means that relief workers (also known as emergency personnel or rescuers) still do not have access to the right information at the right time and in the right format, resulting in problematic and even lethal situations for relief workers and citizens. In the light of Faludi's words, this research is guided by the desire to improve information management in PSNs .

In this context, information management refers to a cycle of processes that support the learning activities of relief workers, including the identification of information needs, acquiring information, organizing and storing information, developing information products and services, distributing information, and using information (c.f., Choo, 2000). In a PSN, information management takes place on several levels, including the individual, agency, team and echelon (i.e., strategic, tactical and operational) level. Poor information management is not only a problem for PSNs in the Netherlands. Evaluation studies of disaster management efforts around the globe have reported similar issues (e.g., Chen, Sharman, Rao, & Upadhyaya, 2008; Dawes, Creswell, & Cahan, 2004). For instance, The National Institute of Standards and Technology (2005, p. 174) concludes that "a preponderance of evidence indicates that emergency responder lives were likely lost at the World Trade Center resulting from the lack of timely information-sharing between agencies". The National Commission on Terrorist Attacks upon the United States explains, "Information that was critical to informed decision-making was not shared among agencies. Chiefs of the fire department that morning told that they were hampered by a lack of information from the New York police department aviation" (Keen et al., 2004, p. 321). In the response to the 2004 Indian Ocean Tsunami, "mostly, the information was incomplete, yet conclusions had to be drawn immediately" (Samarajiva, 2005, p. 737). "During the response to Hurricane 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, p. 61). Next to these examples of poor information quality (IQ), researchers have also reported information system quality (SQ) issues. The 9/11 case for instance 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, p. 57). Other examples of poor SQ include high response times (Horan & Schooley, 2007), inflexible applications (Comfort & Kapucu, 2006) and non-interoperable information systems (Bui & Sankaran, 2001).

These and other examples of poor IQ and SQ provided in this dissertation represent just 'a tip of the iceberg', since statistics indicate that in 2007, 414 natural disasters were documented killing 16847 persons, affecting more than 211 million others and caused over 74.9 US$ billion in economic damages (Scheuren, Waroux, Below, & Guha-Sapir, 2008). Compared to other problems in disaster management such as decision-making (Boin, 't Hart, Stern, & Sundelius, 2005), bounded human cognition (Stern, 2001), sense-making (Weick, 1993) and high uncertainty (Argote, 1982), assuring IQ and SQ in PSNs is an relatively uncharted research topic. While there is some research on addressing IQ and SQ issues in stable business environments (see for instance English, 1999; Eppler, 2006), contributions on assuring IQ and SQ in PSNs were non-existent at the time we started this research.

PSNs can be characterized as 'hastily-formed' (Denning, 2006) networks of many heterogeneous and incompatible public and private agencies that temporarily need to share information under dynamic conditions (Comfort, Ko, & Zagorecki, 2004). These characteristics pose specific challenges for assuring IQ and SQ. Taking occurrences of IQ and SQ problems as *empirical drivers* for this research; the *theoretical driver* is the lack of directly applicable theories for designing information systems that assure IQ and SQ in public safety networks. Previous research does provide two kernel (partially applicable) theories that we can draw upon for measuring and assuring IQ and SQ. These kernel theories include Network Centric Operations (NCO) and Coordination Theory and are explained in Chapter 3. Accordingly, the objective of this dissertation is as follows:

Research Objective: *drawing on NCO and coordination theory, synthesize and evaluate information system design principles that assure higher levels of information and system quality for relief workers during multi-agency disaster response*

The research objective is formulated from a socio-technical perspective (Bostrom & Heinen, 1977a) on assuring IQ and SQ in PSNs. This perspective recognizes the importance of human roles, their tasks and capabilities while emphasizing the role of information technology (IT) as enabling tools within an information system (IS). We share the view that enhancing disaster management requires attention to technological, organizational and social factors and depends on a solid understanding of disaster management as well as the ISs. The literature is awash with definitions and scope of what constitutes an IS. One such definition from a leading IS Journal stood out, as it resonated with the authors' own personal views of what constitutes an IS. Paul (2007) explains that: "An information system is what emerges from the usage that is made of the IT delivery system by the users (whose strengths are that they are human beings not machines)"(p. 194). What is

important when extrapolating from this definition of what constitutes an information system is that there is a significant 'human' dimension that underpins its appropriate and successful use, resulting benefits, costs and risk. Accordingly, our conceptualization of an IS includes the human roles, standards, policies and IT applications needed to manage information effectively within and between relief agencies. We take this socio-technical perspective since we argue that the social and technical subsystems in PSNs are interdependent and must be jointly analyzed, designed and evaluated in order to assure IQ and SQ. Moreover, we expected that this perspective would allow us to gain a holistic understanding of the complex and unpredictable interactions between agencies and supporting technologies in PSNs.

Proceeding with how to achieve the objective stated above, this research employs a prescription driven design science approach. This approach (Chapter 2) consists of four cycles: (1) the rigor cycle (construction of a theoretical knowledge base in Chapter 3), (2) the relevance cycle (empirical analysis in chapters 4 and 5), (3) the design cycle (theory development in Chapter 6), and (4) the evaluation cycle (prototyping and evaluation in Chapters 7 and 8).

Each cycle contributes to existing research on assuring IQ and SQ in PSNs. The first two cycles contribute in understanding IQ and SQ issues in practice and theoretical pathways for finding design principles. A *pathway* is a specific progression of one or more concepts in the evolution of a theory. Each pathway is a dynamic and developmental process, which may include several stages. Following these pathways allows for the synthesis of design principles that are meant to guide IS architects from various relief agencies towards the assurance of IQ and SQ. Next to these pathways, we present qualitative and quantitative data collected from observations, interviews and surveys during our field studies in PSNs. Consolidating the findings from the first two cycles, the latter two cycles contribute an evaluated design theory for assuring IQ and SQ. We call this design theory *'netcentric information orchestration'* since it draws upon the pathways of netcentricity and IT-enabled orchestration. While these pathways are gaining increasing interest for scholars and policy makers, research on translating these pathways into design principles for practitioners and IS architects is non-existent. Accordingly, this research is the first to contribute a set of evaluated design principles (translated in a prototype) that assure higher levels of IQ and SQ. We evaluated the resulting set of principles using a quasi-experimental gaming-simulation with professional relief workers.

Chapter 2 discusses the four cycles of this research more extensively. The remainder of this chapter focuses on demarcating the research focus and explaining the main research concepts as a prelude to the remaining nine chapters. First, we discuss the characteristics of disasters in the next section. Then, the obstacles for multi-agency information management are explained together with the rise of IT for addressing these obstacles. After we present some examples of IQ and SQ issues in PSN, we conclude this chapter with explaining the main research question and the relevance of this research. Parts of this chapter were published in the proceedings of the Information Systems for Crisis Response and Management Conference (Bharosa, Appelman, & de Bruijn, 2007) and the Information Systems Frontiers Journal (Bharosa, Lee, & Janssen, 2010).

## *1.2   Defining disasters and disaster response*

The term disaster often suggests images of extreme events such as earthquakes, tidal waves, floods, hurricanes, and explosions, and yet it is difficult to define a disaster by physical manifestations alone (Auf der Heide, 1989). This means that we need to take a more critical stance towards what a disaster is and how it is different from incidents, hazards and so forth. In the literature the term 'disaster' is interchangeably used with terms such as 'incident', 'hazard', 'crisis', and 'emergency' (e.g., Boin, 2004; Farazmand, 2001; O'Connor, 1987). Even though we did not find any universal distinction between these terms in the literature, there seems to be some distinctive factors such as the scale and type of event. For instance, Pauchant and Mitroff (1992) differentiate an incident from a crisis using the words 'minor' and 'major'. According to these authors, an incident is as minor, localized disruption that can be resolved without harming the larger organizational routine. The term *incident* is more common for denoting industrial accidents (e.g. construction collapse, toxic gas leak) and product/service failure (e.g. machine failure, communications failure). Yet, such incidents are sometimes also referred to as 'technological' disasters (Grunewald, 2003). Even though incidents can also escalate into major events with many casualties, the term incident usually suggest small-scale events with some level of predictability and prior preparation (e.g. in the actors involved, risks and outcomes).

According to Landesman et al., (2005) *hazards* present the probability of the occurrence of a disaster caused by a natural phenomenon (e.g., earthquake, tropical cyclone), by failure of manmade sources of energy (e.g., nuclear reactor, industrial explosion), or by uncontrolled human activity (e.g., conflicts, overgrazing). A crisis on the other hand has the potential to disrupt or affect the entire organization Coombs (1999). The term crisis is often used from a political science perspective to denote a critical point or state of affairs: a military crisis, government policy at the crossroad (Rosenthal, 't Hart, & Charles, 1989), or an economic (financial) crisis. From a managerial perspective, the term 'emergency' is more commonly used to describe such situations, as it is also frequently used by relief agencies such as the police and medical staff. The term emergency puts emphasis on the seriousness of the situation, the unexpected manner of occurrence, and the need for immediate action. Alternatively, the term disaster emphasizes the scale or severity of the event causing the emergency. Compared to emergencies, disasters such be regarded as 'extreme' events having a low probability. Extreme events are occurrences that are notable, rare, unique and profound, in terms of their impacts, effects, or outcomes.

In extreme events, standard procedures cannot be followed and they require a dynamic system to adapt to unanticipated and rapidly changing conditions. Extreme events trigger a greater density of communication and interaction among organizations that stimulates collective action. When extreme events occur at the interface between natural, social and human systems, they are often called "disasters". Acknowledging the existence of many extensive definitions provided in the literature (i.e., Fritz, 1961), we adopt the concise definition provided by Quarantelli and Dynes (1977, p. 32), who define disaster as the "disruption to society after the extreme event". According to this definition, it is not the extreme event (i.e., flood or earthquake) that is the disaster, but the extreme stress on society that it causes. While we prefer this definition because it allows us to capture a wider range of extreme events under the notion of a disaster, we do not aim to extend existing defini-

tions. Instead, we are looking to understand the characteristics of a disaster that shape the environment in which relief workers share and manage information. Table 1-1 adapted from Auf der Heide (1989) outlines some key characteristics of an emergency in comparison with a disaster.

**Table 1-1: Characteristics of emergencies versus disasters (adapted from Auf der Heide, 1989)**

| Emergency response | Disaster response |
|---|---|
| Interaction with familiar faces | Interaction with unfamiliar faces |
| Familiar tasks and procedures | Unfamiliar tasks and procedures |
| Intra-organizational coordination needed | Intra- and inter-organizational coordination needed |
| Roads, telephones, and facilities intact | Roads may be blocked or jammed, telephones jammed or non- functional |
| Communications frequencies adequate for radio traffic | Radio frequencies often overloaded |
| Communications primarily intra-organizational | Need for inter-organizational information sharing |
| Use of familiar terminology in communication | Communication with persons who use different terminology |
| Need to deal mainly with local press | Hordes of national and international reporters |
| Management structure adequate to coordinate the number of resources involved | Resources often exceed management capacity |

In table 1-1, the column on the right outlines some of the main characteristics of disaster response. Note that in practice, the exact characteristics may not be so clear-cut as listed in this table. This means that one or more of the characteristics of emergencies may also be apparent in disaster response and vice versa. Especially when we consider the fact that some disasters actually start as (a combination of) smaller incident(s) and evolved into a disaster (e.g., a small fire in one isolated room of a building with fifteen floors may end up collapsing the entire building and requiring area-wide evacuations). This means that what is a disaster at t=2 (where t is the time), may have been an emergency at t=1. Also, some scholars suggest that almost every disaster involves a high level of novelty to deal with the unexpected under uncertainty and time pressure (i.e., Shaluf, 2007; Shen, Zhao, & Huang, 2008). Hence, it is difficult to sustain that every incident or emergency represents a routine when being well known for each relief worker. In our view, the characteristic that truly distinguishes disasters from emergencies is the configuration of response agencies. Incidents and emergencies can often be handled by a single relief agency, while disasters require the collective resources of multiple agencies. Disaster management usually requires several autonomous public- and private agencies to collaboratively mitigate, prepare, respond, and recover from heterogeneous and dynamic sets of hazards to society (Kapucu, Augustin, & Garayev, 2009). Moreover, incidents and emergencies do not require activation of the strategic and tactical echelons in PSNs, instead activating one or more operational teams (field units) is sufficient for dealing with the situation at hand. While aware of the ongoing debates on the definitions and usage of the terms "disaster," "emergency," and "crisis"

(see for instance Gundel, 2005; Pearson & Clair, 1998; Shaluf, 2007), we use the term disaster throughout this dissertation to refer to the immediate aftermath of a (single or combination of) extreme event(s) threatening public safety that cannot be properly handled by the regular capability of a single local response agency. Therefore in a PSN, a number of response agencies have to coordinate its efforts to effectively deal with the outcomes of a disaster. While we have discussed some distinctions between terms and the characteristics of disaster, we still need to define the process after a disaster in relation to the need for multi-agency information management. Figure 1-1 illustrates the processes in a disaster management cycle.

**Figure 1-1: Disaster management cycle: focus on response**
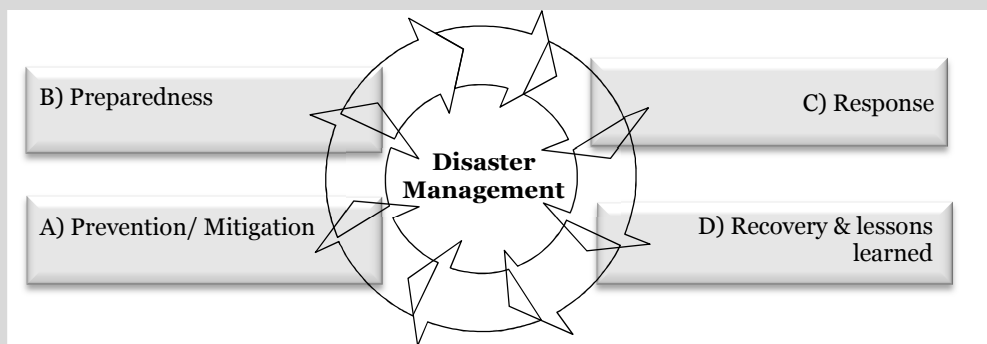


Figure 1-1 illustrates the activities or phases in disaster management. The basic phases of disaster management include: (A) mitigation or prevention, (B) preparedness, (C) response, (D) recovery and lessons learned. *Prevention and mitigation* refer to pre-disaster actions taken to identify risks, reduce these and thus reduce the negative effects of the identified type of disaster event on human life and personal property.

*Preparedness* refers to the actions taken prior to a possible disaster that enable the emergency managers and the public to be able to respond adequately when a disaster actually occurs.

The *response* phase starts when avoidance efforts fail and events trigger a crisis. At this point, organizations shift their resources and efforts to minimizing damage to the environment, facilities and people. Over time, the risk of additional direct damage subsides, and organizations enter the final phase of the disaster management cycle, recovery.

*Recovery* involves attempts to learn from the event internally and "handle" the event externally. While recognizing the importance of every phase in the disaster management cycle, this dissertation focuses on the disaster response phase, especially since most of the IQ and SQ issues reported in the literature have occurred in this phase.

Throughout these four phases, the main goal of relief agencies is to reduce, or avoid the potential losses from hazards, assure prompt and appropriate assistance to victims of disaster, and achieve rapid and effective recovery. Taking the previously stated characteristics of disasters into consideration, we define disaster response as:

> *Disaster response is a complex and partly unpredictable series of multi-agency processes demanding rapid information management within and between echelons in order to support collective decision-making and action in temporary public safety networks*

This definition highlights our focus on the inter-agency (horizontal) and inter-echelon (vertical) information management process as a prerequisite for decision-making and action. Williams (1957) found that the amount of information that must flow through existing channels greatly increased during these phases of a disaster. We proceed with discussing the process of multi-agency information management in the following section.

## 1.3 Four levels of obstacles for multi-agency information management

Information management, including the tasks of collecting, distributing, processing and presenting disaster-related information, is essential for the coordination of disaster response activities (Ryoo & Choi, 2006). Both experimental and field study research suggests that the way in which information is managed within a team affects its performance (Artman, 1999). The content and scope of information management has been under scrutiny by researchers and practitioners from several fields (i.e., business and management, organization research, public administration, communication) for a long time. Consequently, scholars have proposed several definitions and frameworks for information management (e.g., Checkland & Holwell, 1993; Choo, Deltor, Bergeron, & Heaton, 2006). Similar to the process of disaster management, information management is often considered to entail a cycle of activities. Choo (2000) for instance defines information management as "a cycle of processes that support the organization's learning activities: identifying information needs, acquiring information, organizing and storing information, developing information products and services, distributing information, and using information" (p. 14).

For supporting each of these activities, information managers can employ IT applications depending on the services they provide (supply) and their information needs (demand). Often, this way of information management works fine in a single organization, operating in a slowly changing environment and with a predictable information supply and demand. However, during disaster response, the information supply and demand change continuously and are only partly predictable, requiring information managers to adapt resources and flows in order to keep decision-makers informed. Put differently, if an information manager fails to attain and transmit the required information, the whole response system will likely fail to adapt to the requirements of the risk environment in which it operates (Celik & Corbacioglu, 2009; Comfort, Ko, et al., 2004). Previous work has highlighted several obstacles that make multi-agency information management so difficult during disaster response. The explanations can be categorized in four levels: the tasks or work-environment), the community, the agency, and the individual level. We discuss the obstacles on each level in the following sub-sections.

### 1.3.1 The work-environment level: complex and unpredictable processes

Various scholars (e.g., Auf der Heide, 1989; Kapucu, 2006) suggest that information management is so complex because the disaster response environment in which multiple groups of professionals need to collaborate is so unpredictable, dynamic and complex. Bigley and Roberts (2001) state that responding to a disaster, either natural (e.g., floods, earthquakes) or induced by human action (e.g., terrorist attacks) is an extremely complex process in terms of the number of organizations, information systems and the interactions between actors and information systems. Comfort refines this statement by suggesting that disaster response is a very *complex* process because it requires many, and often unprecedented, interactions within and between multiple relief agencies forming a public safety network (Comfort, Ko, et al., 2004). Here, the term 'complex' can have multiple meanings, especially since there is no universally accepted definition for this term (Morel & Ramanujam, 1999). In many cases, the term complex is used to refer to the number of elements in a task, the degree to which a task is programmable, the number of exceptions in the processes and so on (Scott, 1992).

Systems are complex when they have intricate interdependencies among their various elements and many variables operating at the same time (Longstaff, 2005). The relief agencies involved in disaster response can thus be seen as elements, as can their often-divergent points of view and objectives, or the instruments they have available. Consequently, the complexity of a system can be captured using multiple scales, including the number of actors, systems and their interactions changing over time. If we take the non-linear dynamics perspective, a PSN can be viewed as a complex system that is able to learn from its environment and change its internal structure and organization over time, thereby changing the behavior of individual elements (Paraskevas, 2005). We need to keep in mind that, in non-disaster situations, many of the agencies involved operate independently of each other. During disaster response, complexity arises from a variety of elements, systems, processes and actors, and it is hard to get a clear picture of the entire situation within the timeframe of a disaster (McEntire, 2002). In this dissertation, complexity not only refers to the number of actors in the network, but also to the many interactions between them at the various organizational levels (Rao, Chaudhury, & Chakka, 1995). Such interactions are necessary for achieving mutual adjustment and collective mindfulness (Weick & Sutcliffe, 2001). At the community level, information needs to flow in a coordinated fashion through a multi-organizational and multi-level grid, which means that the functioning of the organizations involved not only depends on their internal interactions, but on the interactions with other agencies as well. There may be no central coordinating authority at this level (Denning, 2006). Instead, several, pre-agreed agency leaders at various response echelons coordinate the agencies involved. Many inter-organizational dependencies may not always be clearly visible. These dependencies and the resulting interactions are of crucial importance, as demonstrated by the disorganized multi-agency response to the 9/11 attacks, where police and fire departments were unable to share information (Kean & Hamilton, 2004).

Another often provided explanation in the literature is the high level of uncertainty inherent to disaster response processes. As a complex system, PSNs often exhibit unpredictable or surprising behavior when several forces interact in the system (Longstaff, 2005). The more uncertainty, the greater the number of possible

developments you would have to anticipate. Hence, uncertainty has come to mean the absence of information (Daft & Lengel, 1986). Galbraith defined uncertainty as "the difference between the amount of information required to perform the task and the amount of information already possessed by the organization" (Galbraith, 1973, p. 4). Organizations that face high uncertainty have to ask a large number of questions and acquire more information to learn the answers. The important assumption underlying this approach, perhaps originating in the psychology laboratory, is that the organization and its managers work in an environment where questions can be asked and answers obtained (Daft & Lengel, 1986). Particulary in disaster response situations, this assumption may not hold since answers (in the form of information) may only be available in a later stage of the disaster management process (unfolding events). Moreover, some answers cannot be attained because of the many factors that are related to the cause of the disaster. Morgan and Henrion (1992) claim that there are usually multiple sources for uncertainty that need to be dealt with, including subjective judgment, disagreement, variability and unpredictability. Literature (Meijer, Hekkert, Faber, & Smits, 2006; Walker et al., 2003) suggest multiple dimensions of uncertainty, including nature uncertainty (epistemic/variability), location uncertainty (context/model/input), magnitude of uncertainty (high/low), and the source of uncertainty. Each of these dimensions poses major challenges for relief workers during multi-agency disaster response. For instance, coordinated response is particularly difficult to achieve with threats such as hazardous materials in which the general vulnerability is known, but the specific time, location and magnitude of the threatening event are uncertain (Comfort, Sungu, Johnson, & Dunn, 2001). Even though there are many definitions of uncertainty, the majority of the definitions commonly highlight the implication dealing with incomplete information (Argote, 1982). Therefore, uncertainty, in combination with severe time pressure and limited cognitive attention, makes it difficult for relief workers understand how to improve overall group-level response effectiveness with their supporting activities (Ahituv, Igbaria, & Sella, 1998).

### 1.3.2 The community level: interdependent agencies

Responding to a disaster involves dealing with many hazards and risk, requiring the collaborative resources and capabilities of several relief agencies. Not one single agency involved "has all the necessary resources", nor does any single person possess the expertise in handling all types of extreme events. Therefore, governments have allocated the responsibility of disaster response to Public Safety Networks (PSNs). Also known as a hastily-formed network (Denning, 2006), a PSN refers to a varying set of responding agencies that temporarily need to exchange information in order to deal with the effects of a disaster. In a PSN autonomous agencies collaborate by forming multi-agency (or multidisciplinary) teams that include the personnel of a similar rank and authority of agencies such as the police, fire department, and medical services. In this form of horizontal collaboration, no single person or agency is in command of all others (Mertens, Jochoms, & Zonneveld, 2009). Depending on the country, such teams can be centralized, distributed, or combinations of both. For instance, in the Netherlands the configuration of PSNs is to a large extend predicated by law and follows an hierarchical structure with teams on a strategic, tactical, and operation level (Bharosa, Lee, et al., 2010). The agencies involved in such a network are usually public agencies (i.e., police, fire department, ambulance services), yet the participation of privately owned organizations (i.e.,

security companies, airlines carriers, seaport companies) is not uncommon. While some of these agencies are organized as classic, top down hierarchies, others are organized as more flexible adhocracies.

Organizational researchers, noticeably contingency theorists, argue that there is no one right organizational design and that the right design depends on the specific task at hand (see for example Baligh & Burton, 1981; Lawrence & Lorsch, 1967). Since the various agencies in PSN cover a wide range of tasks, PSNs include a wide range of organizations with varying coordination structures, resources and information needs. PSNs are a unique category of complex organizational networks since they include elements from traditional command and control hierarchies and elements of temporal (hastily-formed) actor networks. For instance, police officers responding to the effects of disasters that they cannot solve on their own (i.e., fires and human casualties), require enough discretion and flexibility, and need to be active problem-solving participants in a variety of cooperation types with relief workers from other agencies (i.e., fire department and medical services). At the same time, they need to work efficiently and exercise hierarchy ("maintaining law and order"). As such, PSNs form a mixture of military hierarchy and network attitudes when responding to disasters. Their complexity can be viewed from many different perspectives, each emphasizing some factors and neglecting others.

### 1.3.2.1   Elements of hierarchical command and control

According to Simon (1996) the classical approach to solving complex problems has been to organize work involving multiple agents and tasks hierarchically. Hierarchical and layered information flows is the style of information management based on the ideal type of bureaucracy developed by the German sociologist Max Weber. This ideal type is based on authority, clear division of tasks, rules, rationality and objectivity. This was the main approach that public sector organizations applied until it became contested in the 1970s. Hierarchies depend on clear boundaries, uniformity and an inflexible structure, which restricted the options of public managers when dealing with complex societal problems. In particular, hierarchies are viewed as emerging, at least in part, as a response to distributed or specialized information (Cohen, 1962). Moreover, it was suggested that advantages accrued to the organization when such divisions exist include a decreased loss of time due to changing jobs, an increased efficiency at doing a subtask (due to learning), and an increased ability to develop machines to help or do parts of the job. In their daily operations, relief agencies work independently in a more or less hierarchy oriented organizational structure (Bigley & Roberts, 2001). Hierarchy is used to establish control, specify tasks, allocate responsibilities and reporting procedures, and presumably gain reliability and efficiency in workflow. This reflects the belief that the most effective repression operations are carried out under rigid control, exercised convergent with intra-agency authority structures. The major decisions are made at the highest (strategic) echelon and are filtered down and more detail is added as they pass through to the lower tactical and operational echelons (top-down/bottom-up principle). In a hierarchy, the flow of information is coordinated through adjacent steps, by controlling and directing information to the higher and subordinate echelons (Malone et al. 1987). Important characteristics of a hierarchical structure are centralized decision-making and authorized (sequential) information sharing (Schraagen, Huis in 't Veld, & de Koning, 2010). The advantage of this coordination approach is that the number of interactions and interdepend-

encies between relief workers is often limited since the linkages are based on long-lasting relationships and procedures. The hierarchical approach to information management is criticized particularly because it is rigid, inefficient with respect to information sharing and has limited flexibility (Drabek & McEntire, 2003). Waugh & Streib (2006) suggest that "a lack of understanding of emergency management is likely one reason why officials suggest that the nation's response to disasters needs a stronger command and control system"( p.131).

### 1.3.2.2  Elements of a temporal (hastily-formed) actor network

When disaster threatens a community, it requires responses from several mono-disciplinary organizations at different locations to set aside prior activities and focus time effort and attention to one common goal (Comfort, et al., 2001). The point of departure is that modern society is characterized by the dispersion of effective problem-solving capacity between different private and public actors with specialized tasks and limited competence. The result is interdependence between different actors, which exchange resources and negotiate collective problem-solving through organizational networks. The ability to form multi-organizational networks rapidly is crucial to humanitarian aid, disaster relief, and large urgent projects (Denning, 2006). Such a network is not only complex, unpredictable and difficult to coordinate; it is also subject to some organizational issues. Moreover, many researchers have noted that networks reflect a qualitatively different form of governance structure than the bureaucratic hierarchies (Powell, 1990). Autonomous agencies that need to spontaneously coordinate information in a network have different characteristics compared to organizations that operate in isolation. From this perspective, PSNs can be understood as webs of relatively stable and ongoing relationships between relief agencies connected by resource dependency, and where information, goals and resources can be exchanged in interactions, so that collective action can be orchestrated towards the solution of common policy (Kickert, Klijn, & Koppenjan, 1999). We use the four characteristics suggested by De Bruijn & Ten Heuvelhof (2000) in order to understand the characteristics of PSNs: pluriformity, interdependency, closedness and dynamics.

   *Pluriformity* implies a high level of variety or diversity, meaning that the actors who form a network are different in many ways, including size, means of power, information processing capabilities and so forth. Major disasters involve multiple autonomous organizations (governmental, NGOs, individuals, communities, and industry). This leads to a diversity of interests, compounded by the fact that many of the data sources and data consumers are neither information technology specialists nor have experience in data management. With the extensive array of participating response agencies, decision-making authority is vested in multiple agencies. Several different organizations play an important role in different areas, but all of them work independently. While there are usually some roles such as Mayor or Minister that on paper have the overall levels of command, there is no single agency that has been identified (and accepted by the others) as a central command and control body responsible for the collective response efforts. As such, there is no single agency that plans, coordinates, controls all aspects of response. Moreover, command and control is usually fragmented by the legal jurisdiction of the different agencies (local, state, federal) and the mandate with which they have been entrusted, their geographic locations, and the overlapping nature of their re-

sponsibilities. This can lead to a vast store of information residing among different agencies and committees, and insufficient sharing of that information taking place. In a multi-actor setting, there is also the issue of *interdependency*. The interdependency between actors suggests that in a network are mutually dependent and these dependencies can be expressed in multiple units, including authority and information. The types of interdependency can vary depending on the context, for instance single-multiple, bilateral-multilateral, synchronous-asynchronous, simultaneously-sequentially and static-dynamic(De Bruijn & Ten Heuvelhof, 2000).

The *closedness* of the participating agencies means that the actors involved are not by definition sensitive to external interventions. Therefore, agencies may not always openly share all information, as they are uncertain of what impact a specific policy, solution, or artifact will have. Prior to the response to the 9/11 attacks, some agencies were reluctant to share information with other agencies in the first place due to security reasons (De Bruijn, 2006). It is well known that individuals under severe stress often forget their recent training and regress to old, ingrained habits (Weick, 1995, p. 102). Richard Strozzi Heckler (1993) call these old habits 'conditioned tendencies'. The old habit is likely to be inappropriate for the current situation and even makes matters worse. In his Masters' thesis, Joseph Pfeifer, a deputy assistant chief in the New York City Fire Department, provides a detailed example of conditioned tendencies instilled by disaster response agencies, which paradoxically can render them incapable of effective response in an emergency (Pfeifer, 2005). Pfeifer was among those responding to the 9/11 disaster in the World Trade Center. His explanation for non-communicative behavior was that organizational bias, referring to ingrained social habits of the separate organizations, prevented emergency personnel from talking to one another. One of these biases is organizational social identity that prefers sharing information within the group but not with outsiders. Under stress, the group members do not think of collaborating or sharing information outside the group, or to take personal responsibility for the welfare of members of other groups (Ibid.).

Finally, PSNs are *dynamic* meaning that as the disaster evolves, new agencies and individuals can join the network. In a disaster environment, new requests are made as the dynamics of a situation unfold. An example is the navigation in a factory is based on static signs. In case of a disaster, routes (doors, staircases and corridors) can be blocked and the static routing system breaks down. In a dynamic environment both the information sources and their content can change over time, potentially creating uncertainty and hampering decision-making. Since disaster response efforts may take days and include different shifts of relief agency personnel, supporting the transfer of information under chaotic conditions is a major challenge for information systems.

Concluding, the composition of these PSNs is often fluid and fluctuates depending on the needs of the organizations involved. Such reconfigurable networks are typically supported by a myriad of ITs that facilitate information sharing across heterogeneous contexts. Since PSNs are based on a recognition of key interdependencies across disciplines and agencies and thus on the need for multi-disciplinary information management to respond to disasters, they also require effective mobilization and utilization of many available community resources (i.e., personnel, equipment, ITs), both public and private.

### 1.3.3   The agency level: organizational silo's and routine workflows

When looking at the *agency level*, it becomes clear that responding to an extreme event requires collaboration and transparency on the part of various agencies with different cultures and organizational structures (Mendonça, Jefferson, & Harrald, 2007). Even though many scholars (e.g., Auf der Heide, 1989; Comfort & Kapucu, 2006) view the organizational structures of relief agencies as military style, hierarchical command and control structures, they are, in fact, not completely similar because various relief agencies face different kinds of challenges under normal circumstances. Some relief agencies are highly disciplined, others disorderly; some have a highly hierarchical structure, while others are more informal and egalitarian; in some cases, authoritarian decision-making prevails, while others tend to adopt a more democratic approach (Granot, 1997). Every relief agency focuses on a different set of challenges in its daily operations and has developed distinct and tailored roles, procedures and capabilities designed to address these challenges. Under normal circumstances, the organizational structures of the separate agencies pose no major problems. However, when disaster strikes, coordination becomes much more difficult, simply because a disaster is more than merely a big emergency (Quarantelli, 1982). So, under the urgent, dynamic conditions of disaster, such hierarchy-oriented organizations (or teams when referring to military organizations) are forced to collaborate and share information in a more network-oriented structure, simply because no single agency has the knowledge and resources necessary for dealing with the wide range of risks emerging during a disaster (cf. Petak, 1985). Accordingly, PSNs are different from military organizations since several, more or less hierarchy-based, yet autonomous organizations need to share information instead of a single hierarchy-based organization with multiple teams. As such, autonomous relief agencies need to rapidly, yet temporarily transform into an interdependent network of agencies.

### 1.3.4   The individual level: bounded rationality & ad-hoc decision making

Finally, the entire information management process needs to support a highly dynamic decision making process. Decision-making is the cognitive process of selecting one option out of a set of possible options. The process begins when the decision maker detects that there is a need to do something but does not know what that should be. It ends when the decision maker has selected an option. The decision maker can be an individual (e.g. the relief agency commander) or a team (e.g. the multi-agency team). Decision-making can be rational, naturalistic, or irrational, and decisions may be based on explicit and/or tacit knowledge. Moreover, the decision-making processes that unfold in such a multi-agency disaster response setting are very information intensive. March and Simon (1958) found that stress and time pressure impede crisis decision makers' search for information. Scholars have suggested a range of contextual, organizational and technical factors to explain why this type of decision-making process is so difficult to support. Consequently, scholars have proposed several descriptive models for describing decision-making processes. Examples include the situational awareness model (Endsley, 1988), the naturalistic decision making model (Zsambok & Klein, 1997), muddling through (Lindblom, 1959), and the recognition primed decision-making model (Klein, 1998). Another often cited model is the sense-making model which emphasizes a

collaborative process of creating shared awareness and understanding out of different individuals' perspectives and varied interests (Weick, 1995).

Among the similarities between the different generic models (normative and descriptive) of decision making, all seem to agree that the identification and implementation of a decision follows the perception of information from the environment and its analysis and understanding. These phases are compatible with the ones included in the classical version of the Boyd's OODA loop. Boyd (1996) identifies four processes: Observe–Orient–Decide–Act, organized into a loop. The OODA loop has been extremely used to represent C2 activities typical of military decisions or of other complex high-risk time-stressed activities like aircraft piloting or firefighting. It has the benefit of simply representing the decision cycle. It also provides taxonomy of the different phases included in the decision-making process. As explained by Klein and Klinger (1991), disaster response is one of those domains in which rational decision making does not work and is not applied because: goals are ill-defined and shifting, the environment is highly dynamic, information is incomplete, decision makers are under time pressure, and stakes are high. Note that we are not investigating the most complete or accurate model for describing decision-making processes during disaster response. Instead, this section aims to capture the main characteristics of the decision-making process that information systems need to facilitate during disaster response. As discussed later in Chapter 4, the characteristics are important for preparing our field study observations.

There is no shortage of literature on the obstacles decision makers face during this process. Smart & Vertinsky (1977) underline the ad-hoc group decision-making environment in which response teams have to operate. Deciding and acting during disaster response is a challenging process for each individual, because everyone is faced with severe time-pressure and a flood of information that may be inaccurate or outdated by the time a decision or action takes place. Such a complex, intense and information-rich environment can easily result in cognitive overload at an individual level (Greef & Arciszewski, 2007), because a decision-maker's mental capacity (due to the extended time to concentrate and the sheer number of available alternatives to consider) is limited (Lindblom, 1968; March, 1988). This cognitive overload is related to a human limitation that is known as 'bounded rationality' (Simon, 1982) and that constitutes a well-known bottleneck in human information processing. Cognition is related to role performance or, in other words, the execution of a set of behaviors that an individual is expected to be able to perform (Mendonca, Jefferson, & Harrald, 2007).

This negative relationship between information requirements and cognitive capacity (Galbraith, 1977) exists at the individual level, resulting in a performance level that may not correlate with the amount of information available (Rao, et al., 1995). As such, it is important to determine how much information people need and can be exposed to at an individual level with regard to disaster management. In addition, the task environment is often extremely complex since there are many agencies and systems involved that interact in unpredictable ways (Celik & Corbacioglu, 2009). Moreover, there is a tremendous urgency and time pressure surrounding the decision-makers (Boin, et al., 2005). Also uncertainty pertaining subsequent events, risks, resources and hazards, dominate the entire decision-making process (Bui & Sankaran, 2001; Chen, Sharman, Rao, & Upadhyaya, 2007). Combined, all these factors require disaster response processes, including decision-making and information management processes, to adapt to changes in the re-

sponse environment. In this way, information management processes may both support or impede decision-making adaptability. Often, relief agency commanders are primarily responsible for making many decisions and, therefore, do not have much time to devote to systematic information management.

## 1.4    The increasing use of IT in Public Safety Networks

Driven by the conclusions of various disaster evaluation reports, both scholars and practitioners are showing an increasing interest in the development and use of information technology (IT) for addressing the obstacles mentioned in the previous section. Some scholars have even argued that IT is essential to improving information sharing and decision making for emergency responders (i.e., Graves, 2004). In addition to traditional channels for information sharing such as telephone, face-to-face meetings, and memorandums, IT-based solutions such as electronic mail, digital maps, bulletin boards, computerized conferencing systems, electronic meeting systems, document delivery systems, and workflow management systems are increasingly being used during disaster response (van de Walle & Turrof, 2008). Table 1-2 outlines a crude classification of these technologies based on the functions they provide for relief agencies.

### Table 1-2: IT innovations for disaster response

| Function | Information technology | Contributions |
| --- | --- | --- |
| Location, navigation and tracking | Geographic Information Systems | Van Oosterom et al. (2005), Kelmelis et al. (2006) |
| | Geo-Collaborative tools (Geo-CSCW) | Cai, MacEachreen, Brewer, McNeese (2005) |
| Information foraging and sharing | Smart Dust, Wireless Sensor Networks, Wearable Computing | Lorincz et al. (2004); Kumar et al. (2004); Randell (2008) |
| Risk management | Risk calculation and simulation technology | Berghman (2008), Berrogi & Wallace (1995) |
| Coordination and feedback | Collaborative virtual workplaces | Collins et al. (2008) |
| | Agent-based systems | Lui (Liu, 2004) |
| Decision-making | Decision support systems (DSS) | French & Turoff (2007) |
| | Intelligent mobile systems | Deltor & Yuan (2005) |
| Knowledge repositories | Shared data spaces | Larson, Metzger, Cahn (2006) |
| | Content Management Systems & Knowledge Systems | Atoji, Koiso & Nishida (2000), Raman, Ryan & Olfma (2006) |
| Citizen/Community participation | Community response grids, WIKIs, social networks, micro blogging | Jaeger et al. (2007), Palen, Hiltz & Lui (2007) |

According to Stephenson and Anderson (1997), IT developed primarily by defense departments or universities has been introduced in the field of public disaster management since the late 1970s. In the period between the 1970s and 1980s, the development of the microprocessor enhanced the computing capacity of many public agencies. In this period, designers focused on the development of standalone applications driven by functionality. Evernden & Evernden (2003) characterize this period as the first generation of information architectures based on simple frame-

works. In the 1980s most information systems development efforts have been limited to computer-based replacement of manual information systems within an organization (Barrett & Konsynski, 1982). In the late 1980s, the emergence of decision support systems promised more innovative use of information. For instance, Drabek (1991) demonstrated that microcomputers provided local disaster managers with a powerful tool that could enhance interagency coordination. Some operational applications included real-time information exchange. Drawing on IT innovations from the last decade, scholars have proposed a wide range of new tools and technologies to support disaster response.

Starting the early 1990s, innovations in computer infrastructures have revolutionized the way information between multiple agencies could be gathered and exchanged. At the time, the potential of IT as means for organizing resourced during disaster was already recognized (Calloway & Keen, 1996). In this era we found that information technologies, ranging from digital libraries to the internet to multilayered geographical information systems transformed the processes in disaster management (Dash, 1997; Gruntfest & Huber, 1998). The digitalization of information leverages multiple possibilities for coordination, cooperation and collaboration between agencies. Information systems became more complex and interdependent, supporting mainly organization specific work processes. Technologies such as the World Wide Web (based on the concept of hypermedia) enable organizational members to link and share multimedia documents across time zones and distance both from within and outside the organization (Turoff, Rao, & Hiltz, 1991). The use of technologies in ISs allow people to create, annotate, link together, and share information from a variety of media such as text, audio, video, and images.

Most of the innovations listed in table 1-2 draw on Geographic Information Systems (GIS) and Decision Support Systems (DSS). Repositories of knowledge are also extendedly used for disaster response enabling keeping track of experts who should be contacted. Recently, ad-hoc usage of Internet also enabled citizens to take part in crisis response and collaborate by exchanging information, comments, photos and so on (Palen, Liu, Hiltz, 2007). It is expected that Wearable Computing, a form of pervasive IT, will be used in disaster management (Randell, 2008). Generally, the technologies listed in this table suggest a trend of further end-user (relief worker) empowerment. Research on IT for disaster response is generally normative and questions the technological fit to disaster response. Some studies criticize the lack of reliability of the technologies deployed for disaster response. For instance, IT infrastructures are sometimes not available during disaster response, which is likely to disturb coordination (Quarantelli, 1997). Helsloot (2005) for instance reports problems on the level of unreliable communication technology hampering inter-agency message exchange. Other studies address technological flexibility (Allen & Boynton, 1991) to turbulent environment (Allen & Boynton, 1991. Criticism also targets IT design. IT interfaces are not always user-friendly, which is likely to slow down the crisis response (Landgren, 2007). Graphical representation is crucial for disaster response but it is also criticized (Mendonça, 2007). The risk of information overload also obstructs the ability to take decisions in disaster response quickly (Dearstyne, 2007).

IT use is also problematic in disaster response because some IT functionalities obstruct user practices (Dawes et al., 2004). For example, many-to-many communication can require that users permanently stay connected during disasters. Such a constraint implies a technical effort or it slows down local action (Jae-

ger et al., 2007). Likewise, this functionality also creates a dependency to technology that may be risky: lack of data or loss of access to information bewilders organizations during disasters (Hutchins, 1991).

Carver & Turoff, (2007) explain, "…technology is vital in extending our human capabilities to cope with either natural or man-made disasters, but we forget the human role at our peril. This means the human as part of the system, the computer as part of the team, and both the computer and the human working with other people and other computer systems in other agencies, sharing information and working together to manage the emergency, mitigate its effects, and to support the victims after the event" (p.34). This fits the socio-technical perspective and definition of ISs discussed in the introduction. Studies in this area have also concluded that the use of ITs increase participation and result in better quality decisions since decisions are made by consensus and not by domination (Hiltz & Turoff, 1993). ISs based on advanced ITs seem to facilitate relief workers in recognizing, understanding, defining, investigating, evaluating, and solving a problem as a team (van de Walle & Turrof, 2008). This promotes greater learning and understanding of both internal and external issues during disasters. IT allows the joint construction and distribution of experiences and insights. ITs can also support feedback and review mechanisms among team members. Thus, they not only support communication but also collaboration. Yet, the use of IT and the effects of the use on performance can greatly vary from one response situation to another (Hiltz & Turoff, 1993).

## 1.5 Information quality and system quality during disaster response

The previous section presented some advances in the use of IT in PSNs. In spite of these developments, two major symptoms resulting from information management practices still pose significant challenges for relief workers: the information quality and the system quality. Taking IQ and SQ problems as the *empirical driver* for this research, the *theoretical driver* is the lack of theories for designing information systems assuring IQ and SQ in PSNs. We introduce both concepts in the following sub-sections; a more detailed discussion on these concepts follows in Chapter 3.

### 1.5.1 The characteristics of information as a product

During the process of multi-agency disaster response, information is one of the essential needs of relief workers (Helsloot, 2005). Fisher and Kingma (2001) reveal that one main factor behind the explosion of the NASA space shuttle Challenger on 28 January 1986, and the shooting of an Iranian Airbus by the US Navy Cruiser USS Vincennes on 3 July 1988, was poor quality information. Given how fast information can become outdated, information management during the actual response is critical in order to continuously have the most recent information at one's disposal. Emergency managers have learned that accurate and timely information is as crucial as rapid and coherent coordination among the responding agencies (van de Walle & Turoff, 2007). Moreover, because disaster response processes are information-intensive (De Bruijn, 2006), the effectiveness of relief agencies largely depends on the quality of the information they have available (Davenport & Prusak, 1998). Table 1-3 lists some of the IQ dimensions and related issues mentioned in the literature on disaster response efforts.

## Table 1-3: Examples of IQ issues mentioned in the literature

| IQ dimension | Description of IQ issues mentioned in the literature |
| --- | --- |
| Accuracy | "In disaster management, information about technical conditions may be ambiguous and unreliable" (Kontogiannis, 1996, p. 76). "Disasters start out with a lack of information, which then turns into large amounts of imprecise information" (Manoj & Hubenko Baker, 2007, p. 52). |
| Timeliness | "Sending us very stale situation report 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, p. 197). |
| Relevance | Relevant information, that is information suited to its intended use, was needed to support emergency and recovery operations of all kinds (Dawes, et al., 2004). |
| Quantity | When a large-scale disaster happens, a great deal of information occurs in a short period of time (Atoji, et al., 2000), resulting in too much information to process (Jenvald, Morin, & Kincaid, 2001) and straining the capacity of the emergency management and communication systems (Manoj & Hubenko Baker, 2007). |
| Completeness | In the response to the 2004 Tsunami, "mostly, the information is incomplete, yet conclusions must be drawn immediately"(Samarajiva, 2005, p. 733). During Katrina, the federal government lacked the timely, accurate, and relevant information necessary to evaluate which critical infrastructures were damaged, inoperative, or both (Townsend et al, 2006). |
| Format | During the response to 9/11, 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). |
| Security | Sharing information during an emergency is challenged by trust and security issues (Manoj & Hubenko Baker, 2007), because of the need to protect potential misuse of information; however, excessive regulation hampers responders from getting useful information from other agencies (Kim, Sharman, Rao, & Upadhyaya, 2007). |
| Consistency | Firefighters rushing to the Schiphol 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). If several information systems suggest different location coordinates, this inconsistency delays decision making (Fisher & Kingma, 2001). |
| Availability | During Katrina, access to information 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 1-3 indicates that IQ is a multi-dimensional concept, describing properties of the information received, capturing a wide range of variables such as accuracy, timeliness, completeness, consistency, relevance and quantity (Wang & Strong, 1996). Miller (1996) adds format, compatibility, security, and availability of information as important variables for measuring IQ. The examples provided in Table 1-3 are not exhaustive and are based on the reports of scholars and investigators. Accordingly, other IQ issues may have occurred during the respective disasters.

The multi-disciplinary and specialist character of the work relief workers are involved in poses special requirements for interdisciplinary information exchanges. For instance, the relevance of information is hard to assess for all relief workers in the PSN, leading to situations where all information is exchanged (just in case), or situations where relevant information is held back caused by the inability to assess the relevance of all information for all actors. Moreover, certain events, when viewed in isolation, may at first appear irrelevant during disaster response, but when analyzed collectively may identify a potential threat (Adam et al., 2007). Chapter 4 continues with a more elaborate discussion of the dimensions of IQ.

### 1.5.2 System quality: the characteristics of the information system

In the context of disaster management, both the information demand and supply keep changing over time. As a result, flexibility and interoperability are particularly important requirements for decision-support applications. Information 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). Compared to information quality (IQ), system quality (SQ) refers to the quality of the information system (as a producing system) and not of the information (as a product) (Delone & McLean, 1992). As agencies have their own information systems, information sources are usually heterogeneous and require standardization for compatibility (Bui et al., 2000).

Sawyer (2007) indicates that there is great variety in types of information systems being developed under the umbrella of "public safety network" and the types of services delivered. This variety includes technological feature sets, organizational arrangements, governance practices, jurisdictional scope, and institutional environment. One key commonality is that all involve multiple agencies, meaning they may span governmental levels (i.e., federal, provincial, local), functions (e.g., police, fire, justice), or geographies (i.e., municipalities, regions or communities). In such a setting, the lack of SQ can have significant impacts on the response efforts. For instance, the lack of interoperability between communication equipment used by different public safety agencies and jurisdictions plagued rescue teams and relief workers during disasters (Portman & Pirzada, 2008). The 9/11 commission report for instance noted that a patchwork of incompatible IT and the uncoordinated use of frequency bands were the main reasons for nonexistent or poor interagency communication during emergency response and recovery operations (Kean & Hamilton, 2004). Shouting, waving signs, and runners with hand-written messages were often the only primitive alternative (Ibid.). While these forms of 'primitive' information sharing do allow for the continuation of disaster response efforts, they do not provide information management capabilities necessary to share more complex types of information (e.g., geographic maps with ship locations) to be

shared, enriched and validated across a large network of physically distributed agencies. In order to avoid the fallback to such preferred forms of information sharing, stakeholders (e.g., information system architects, relief workers and policy makers) actively solicit for means that help assuring SQ during disaster response (ACIR, 2005; ASE, 2008; National Research Council, 2007; Townsend et al, 2006). Table 1-4 lists some of the SQ dimensions and related issues mentioned in the literature on disaster response efforts.

| Table 1-4: Examples of SQ issues mentioned in the literature ||
|---|---|
| **SQ dimension** | **Description of SQ issues mentioned in the literature** |
| 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, p. 57). |
| 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, p. 86). |
| 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, p. 123). "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, p. 313). |
| 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 inability to connect multiple communications plans and architectures clearly impeded coordination and communication at the Federal, State, and local levels" (Townsend et al, 2006, p. 56). |

Similar to Table 1-3, Table 1-4 is not exhaustive and is meant to give an impression of the type of SQ issues relief workers have struggled with during real disasters. These examples emphasize the need to correct decades of isolated, ad-hoc, and poorly supported IT development practices among and within relief agencies. Having introduced the concepts of IQ and SQ, the next section presents the main research question of this dissertation.

## 1.6    Main research question

The previous sections conclude that the assurance of IQ and SQ is both necessary and complicated. The absence of principles for assuring IQ and SQ in previous work drives this dissertation. As a coherent package of ITs, human roles, standards and procedures, scholars have demonstrated the information systems can improve disaster response efficiency and effectiveness. Yet, literature provides little guidance to stakeholders (e.g., information system architects, policy makers, software vendors) when it comes to assuring IQ and SQ during disaster response. Since this dissertations aims to guide these stakeholders on assuring IQ and SQ, we employed the prescription oriented design science research approach (Hevner & Chatterjee, 2010). Chapter 2 provides a more detailed description of this approach.

Following the design science research approach also allowed us to start this investigation based on a first hunch about the problem and solution space. Scholars such as Simon (1973) and Verschuren & Hartog (2005) advocate starting from a first hunch when investigating unstructured or 'wicked' problems with several problem aspects and solutions spaces (see discussion in Chapter 2). Our first hunch was that the disaster driven aggregation of heterogeneous ISs does not leverage the necessary information management capabilities for assuring IQ and SQ across a network of agencies. Instead, inter-agency and inter-echelon information management activities need to be coordinated in concert. This hunch led us to study coordination theory. As discussed in Chapter 3, this theory holds several pathways that helped us to synthesize principles for assuring IQ and SQ. A *pathway* is a specific progression of one or more concepts in the evolution of a theory. Each pathway is a dynamic and developmental process, which may include several stages.

Another theory that provides such pathways is Network Centric Operations (NCO). This theory originating from the design of ISs for military purposes, has also captured the interest of policy makers and IS architects in PSNs (see chapter 5). While scholars such as Stanovich (2006) have considered the transformation of existing command and control based hierarchies to network centric based structures, literature on the implementation and evaluation of NCO was absent at the start of this research. Compared to the well-established knowledge base on coordination theory, NCO was still an ill-studied set of concepts. Nevertheless, the pathways provided in this theory invited us to consider it as a kernel theory. In line with the research objective (page 12) the main question guiding this research asked:

*Which information system design principles assure higher levels of information quality and system quality for relief workers in public safety networks during multi-agency disaster response?*

Chapter 2 further decomposes this main research question discussed the research instruments taken to answer the sub questions. The formulated research question suggests that the main deliverable of this dissertation is a set of design principles. When treating ISs as socio-technical systems the notions of IS architectures and guiding principles can be used to conceptualize and specify the IS design (Richardson, Jackson, & Dickson, 1990). While an IS architecture conceptualizes the object or artifact of design, principles embody the generic prescriptions for the design and implementation of IS (Housel, El Sawy, & Donovan, 1986). Chapter 6 explains the use of principles in the design of information systems in more detail. The next section outlines the chapters in this dissertation.

## *1.7    Outline of this dissertation*

Figure 1-2 depicts the relation between the various chapters in this dissertation.

**Figure 1-2: Outline of chapters**
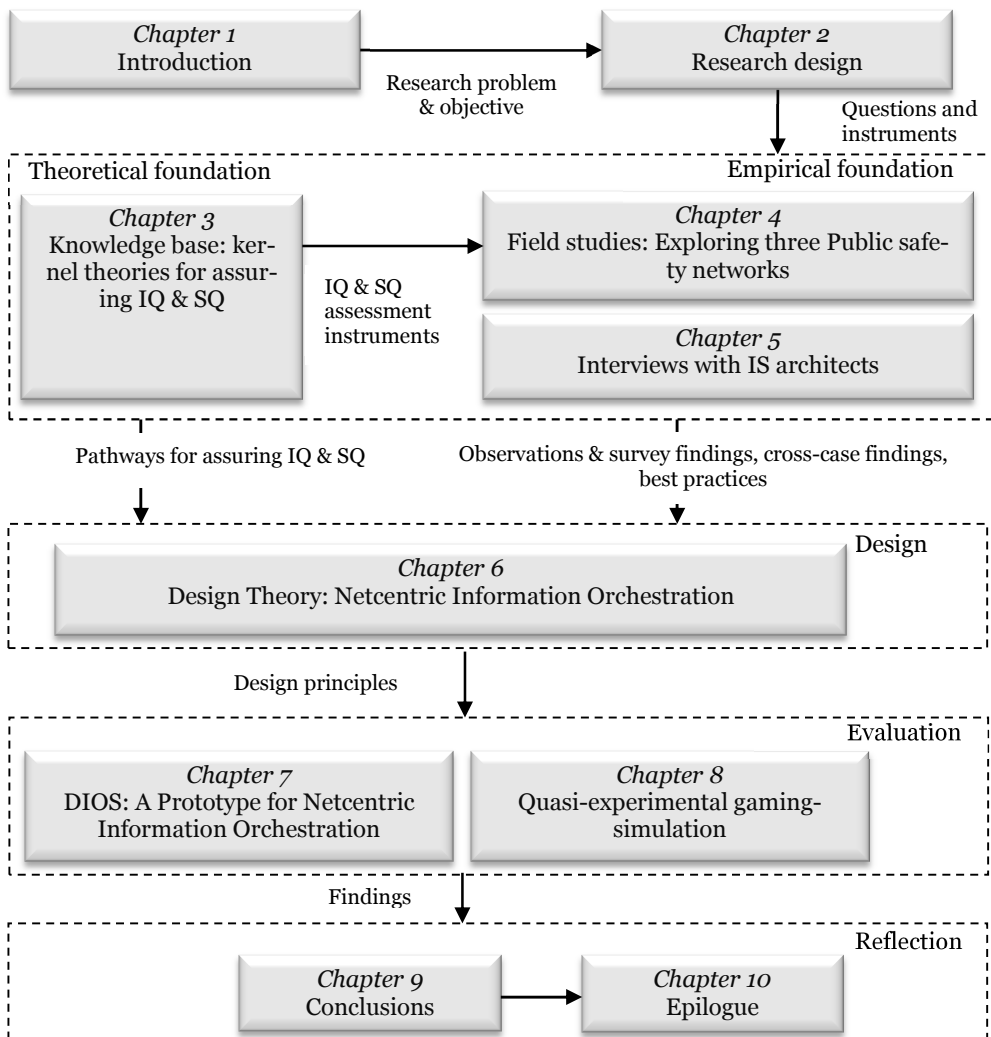


This dissertation proceeds by presenting the research approach in Chapter 2. Chapter 3 presents the theoretical foundation of this research. Chapters 4 and 5 present the empirical foundation of this research. Drawing on the theoretical and empirical foundations, Chapter 6 presents our design theory, which we later evaluate in Chapters 7 and 8. After discussing the main findings of this research in Chapter 9, Chapter 10 concludes this dissertation with a reflection on the main findings and research approach, followed by some avenues for future research.

# 2 Research approach

*Scientists try to identify the components of existing structures, while design-ers try to shape the components of structures* (Christopher Alexander, 1969).

*Design science researchers try to combine both* (this dissertation).

## 2.1 Introduction

As we have discussed in the previous chapter, the objective of this research is to synthesize and evaluate information system design principles that assure infor-mation quality (IQ) and system quality (SQ) for relief workers during multi-agency disaster response. Achieving this objective is difficult for three reasons. First, there is little empirical data on the design of information systems for disaster response. The scarcity of data in this domain can in part be attributed to the fact that disas-ters are unplanned and dangerous events, limiting the opportunity for researchers to collect data on site (Killian, 2002). The majority of research in this domain con-sists of ex-post investigations describing and explaining the process and outcomes of disaster management efforts. Second, there are no directly applicable theories on assuring IQ and SQ that we can apply and evaluate (for instance through hypothe-sis formulation and data analysis). Finally, assuring IQ and SQ for relief workers is a 'wicked' or ill-structured problem (cf. Checkland, 1981; Simon, 1973). This means that there are several stakeholders, problem components (e.g., organizational, technical, institutional), and potential solution spaces (e.g., rules, network struc-ture, technologies) that need to be considered when examining the information systems in Public Safety Networks (PSNs).

Ill-structured problems are complex and nonlinear. This means that small changes in input can create massive changes in outcome, and the same action per-formed at different times may create entirely different results. Ill-structured prob-lems have no "stopping rule" or end state and limitations of time and resources terminate this infinite search. Rather, the researcher must seek a "good enough" solution based on maintaining equilibrium around some acceptable conditions (i.e., IQ and SQ values). Understanding the problem and conceiving a solution are iden-tical and simultaneous cognitive processes. Therefore, it is vital that problem-solving processes are structured and facilitated so that the best solution is achieved within pre-established limits. Rowe (1987) states that human problem solvers are rarely in a position to identify all the possible solutions to a design problem and settle for choices that satisfy the problem definition at a certain point in time. Si-mon (1969) refers to this search for solutions as "satisficing" (p. 64). Addressing ill-structured problems require that the researchers grasps, or achieves a new under-standing of, the problem structure or the relations of aspects within a problem (Dominowski & Dallob, 1995, p. 38). Alternatively, it could be said that researchers require a creative approach (Finke, Ward, & Smith, 1992, p. 169).

One coherent research methodology that allows researchers to understand and solve ill-structured problems in a creative yet rigorous manner is the design

science research approach. This approach implements Kurt Lewin's proposition: "if you want truly to understand something, try to change it" (Lewin, 1958, p. 201). This approach is not simply about changing, but also improving an environment. While the origins of this approach can be traced as far to Simon (1969), this approach really took off after the seminal publication by Hevner, March & Park in 2004. We use this recently revived approach in the information systems domain since it allows us to focus on structuring the problem under investigation (i.e., information systems for multi-agency information management in PSNs), prescribing a satisficing solution (i.e., set of design principles) and evaluating the solution. Moreover, this approach provides researchers an opportunity to go beyond explanation, towards research that generates design knowledge relevant for practitioners, which is implicitly a driver for conducting this research. This chapter continues with an elaboration on our design science research approach, including the research philosophy, research questions and instruments. Part of this chapter was published in (Bharosa, Bouwman, & Janssen, 2010).

## 2.2  *Research philosophy*

A research philosophy consists of all the ontological, epistemological and axiological assumptions made by a researcher pursuing an intellectual endeavor (Gregg, Kulkarni, & Vinze, 2001). It determines the boundaries of the knowledge that is obtainable and the limits of the obtained knowledge. Since a research philosophy guides a researcher when choosing a research strategy and research instruments, we need to define our research philosophy. In doing so, we first need to briefly discuss the three dominant research philosophies used in research on information systems: positivism, interpretivism and design. Positivists claim that reality can be observed objectively and described using measurable properties without interfering with the phenomenon being studied. Orlikowski & Baroudi (1991) classify information systems research as positivist if there is evidence of formal propositions, quantifiable measures of variables, hypothesis testing and the drawing of inferences about a phenomenon from a sample to a stated population. In the information systems community, one of the main critiques on the positivistic research paradigm is that it neglects the complexity of information systems. As stated in the first chapter, we consider information systems as socio-technical systems, covering the interaction between human actors (i.e., relief workers) and technology components (e.g., software application). Information systems, particularly those that need to be operated in a multi-agency environment, are complex, artificial and purposefully designed. They are composed of people, structure, technologies and work systems (Alter, 2003). Hence, technology and human behavior are not dichotomous and are inseparable in an information system.

An increasing awareness of the complexity of information systems has prompted researchers in this field to accept interpretivism as a valid approach to guide their research. Interpretivists adopt a relativistic ontology that states that reality is a subjective construction of the mind, that socially transmitted concepts and names direct how reality is observed as do language and culture (Gregg, et al., 2001) and that it is possible to have multiple interpretations of reality. The main critique for the interpretive approach is that this approach is more suited in a preliminary or heuristic stage, which takes place before the actual research (using statistical hypothesis testing) takes place (i.e., Kaplan & Duchon, 1988; Trauth & Jessup, 2000). At the extreme, positivism would hold that any field of study, in or-

der to qualify as scientific, must be nomothetic and therefore work towards the ideal of discovering universal or general laws; at the same time, interpretivism would hold that the goal of universal laws is inappropriate in the study of human affairs because individuals, groups, and other social units are all unique and therefore demand idiographic theorizing instead (Lee & Baskerville, 2003). An idiographic approach is based on what Kant described as a tendency to specify, and is expressed in the social sciences. It describes the effort to understand the meaning of contingent, accidental, and often subjective phenomena.

In 'History and Natural Science' (Windelband & Oakes, 1980) , the neo-Kantian Wilhelm Windelband proposes a distinction between the study of the general in the form of the natural law (nomothetic sciences) or the particular in the historically determined form (idiographic sciences). They consider in one part the ever-enduring form and in the other part the unique content, determined within itself, of an actual happening (Babbie, 2009). The one comprises sciences of law, the other sciences of events; the former teaches what always is, the latter what once was. A paradigm recently gaining a lot of interest in the field of information system research is the design science paradigm (Hevner & Chatterjee, 2010). Design science is a more "creative" paradigm, since it is a research perspective that involves analyzing the use and performance of designed artifacts to understand, explain, and, very frequently, to improve on the behavior of aspects of information systems (Vaishnavi & Kuechler Jr., 2008). The following table outlines the philosophical differences between the three major paradigms.

**Table 2-1: Dominant research philosophies (Vaishnavi & Kuechler Jr., 2008)**

| | Research perspective | | |
|---|---|---|---|
| **Basic belief** | **Positivist** | **Interpretive** | **Design** |
| Ontology | A single reality, knowable, probabilistic | Multiple realities, socially constructed | Multiple, contextually situated alternative world-states, socio-technologically enabled |
| Epistemology | Objective; dispassionate Detached observer of truth | Subjective (i.e., values and Knowledge emerge from the researcher-participant interaction) | Knowing through making (i.e., prototyping), objectively constrained, construction within a context, iterative circumscription reveals meaning |
| Methodology | Observation; quantitative, statistical | Participation; qualitative. Hermeneutical, dialectical | Developmental, measure artifactual impacts on the composite system |
| Axiology: what is of value | Truth: universal and beautiful; prediction | Understanding: situated and description | Control, creation, progress (i.e., improvement), understanding |

While positivism and interpretivism are useful paradigms for numerous types of studies, both are more concerned with theory testing in a specific organiza-

tional setting than with developing or extending new theories and technologies. We agree with Gregg et al., (2001) who argue that the positivist and interpretive research paradigms do not consider software or system development as part of building required knowledge processes. For the purpose of our study, we need to follow a paradigm that allows us to extend the boundaries of information management capabilities by creating new and innovative artifacts. This purpose guided our interest towards the 'relatively new' design science paradigm. We say relatively new because this approach has its roots in the early work of Herbert Simon (1969), it has only gained significant attention (1541 hits in Google Scholar) since the seminal MIS Quarterly publication by Alan Hevner and colleagues in 2004. Drawing from Kuhn (1970) and Lakatos (1978), research can be very generally defined as an activity that contributes to the understanding of a phenomenon. In the case of design research, all or parts of a phenomenon may be created as opposed to naturally occurring (Vaishnavi & Kuechler Jr., 2008). We continue elaborating on this research strategy and choice of instruments following in the next section.

## 2.3  Design science research strategy

Design science has its roots in engineering and the science of the artificial (Simon, 1969). It can be considered as a problem-solving paradigm (cf. Sol, 1982) ) with the emphasis on the end products and the solution (Rossi & Sein, 2003). Design research is a normative science that focuses on creating an artifact (e.g., organization, information system) to obtain given goals. According to Simon (1969), design "is concerned with how things ought to be, with devising structures to attain goals" (p.133). The prescriptive design research paradigm should result in "a prescriptive design theory which integrates normative and descriptive theories into design paths intended to produce more effective information systems" (Walls, Widmeyer, & El Sawy, 1992, p. 41). Hevner et al. (2004) argue that the end products of a design science cycle may include: (1) constructs or concepts, e.g., vocabulary and symbols, that define the terms used when describing an artifact, (2) models, e.g., abstractions and representations, that are used to describe and represent the relationship among concepts, (3) methods, e.g., algorithm and practices, that are used to represent algorithms or approaches on how to do a certain task, and (4) instantiations, e.g., implemented or prototyped systems, that are used to realize the artifact. Following this approach the researcher starts with a relevant problem and designs by an iterative search process and by building identifiable artifacts (construct, method, model, system) followed by evaluation (utility and efficacy must be evaluated rigorously).

Figure 2-1 outlines the main research cycles, research questions (RQ), units of analysis and measurement instruments in accordance with the design science framework by Hevner et al. (2007). Three cycles are emphasized in this framework, a relevance cycle, a rigor cycle, and a design cycle. Good design science research often begins by identifying and representing opportunities and problems in an actual application environment (Hevner & Chatterjee, 2010, p. 17). Thus, the *relevance cycle* initiates design science research with an application context that not only provides the requirements as inputs for the research (e.g., the opportunity/ problem to be addressed) but also defines acceptance criteria for the ultimate evaluation of the research results. Translated to this research, the application context is disaster response in PSN and the acceptance criteria are the set of IQ and SQ variables deemed important (see chapter 1). An important question here is, does the de-

sign artifact improve the IQ and SQ in PSN and how can this improvement be measured? The output from the design science research must be returned into the environment for study and evaluation in the application domain, in our case PSNs.



**Figure 2-1: Research framework (based on Hevner et al., 2007)**

The *rigor cycle* depicted in figure 2-1 provides past knowledge to the research project to ensure its innovation. It is contingent on the researchers to thoroughly research and reference the knowledge base in order to guarantee that the designs produced are research contributions and not routine designs based on the application of known design processes and the appropriation of known design artifacts (Hevner & Chatterjee, 2010, p. 18). While rigorous advances in design t separate a research project from the practice of routine design, we need to be careful to identify the sources and types of rigor appropriate for design research.

The internal *design cycle* is the heart of any design science research project. This cycle of research activities iterates more rapidly between the construction of an artifact, its evaluation, and subsequent feedback to refine the design further. Simon (1996) describes the nature of this cycle as generating design alternatives and evaluating the alternatives against requirements until a satisfactory design is achieved. As discussed above, the requirements are input from the relevance cycle. The design and evaluation theories and methods are drawn from the rigor cycle. According to Van den Akker (1999) "the major knowledge to be gained from design

research is in the form of (both substantive and methodological) 'design' principles to support designers in their task. Obviously those principles cannot guarantee success, but they are intended to select and apply the most appropriate knowledge for specific design and development tasks" (p. 9). We return to the value of principles in section 2.6.

Considering these three cycles, we can conclude that design science research emphasizes the interplay between theory, methodology and empirical data. The benefits of this interplay is clearly phrased by Blumer (1954, p. 1): "Theory, inquiry and empirical fact are interwoven in a texture of operation with theory guiding inquiry, inquiry seeking and isolating facts, and facts affecting theory. The fruitfulness of their interplay is the means by which an empirical science develops." The selection of research instruments in each cycle depends on the amount of existing theory available, on the nature of the research (i.e. the problem type), the research objective and on the types of research questions (March & Smith, 1995). In accordance with figure 2-1, three research cycles can be expected: (1) construction of a knowledge base, (2) empirical analysis of the problem, and (3) theory (i.e., design principles) development and evaluation. While Hevner et al. (2007) also refer to a separate evaluation cycle; they do not consider evaluation as separate cycle. Instead, evaluation they consider evaluation as an integral part of the design cycle. Acknowledging the tight coupling between design and evaluation, we consider our evaluation approach as a separate cycle. We elaborate on the cycles in the next subsections.

## 2.4 Rigor cycle: construction of the knowledge base

The main activity in the rigor cycle is the construction of the knowledge base. The knowledge base contains the accumulated body of knowledge pertaining the phenomena of interest, the existing artifacts aimed at achieving the given purpose, and their evaluations, which are based on previous research. It contains the results of prior design research in the form design ideas, techniques and tools (Hevner, et al. 2004). Considering that the objective of this dissertation is to prescribe evaluated design principles for assuring IQ and SQ, we need to establish two foundations in our knowledge base. The first foundation is on defining and measuring IQ and SQ. Studies that have investigated major disaster response efforts mention several examples of poor IQ and SQ. Yet, since these studies focused on the performance of relief agencies, investigators have left both constructs ill-defined and without assessment measures. Even though we intuitively knew what IQ and SQ mean, we still need a framework that allowed us to investigate IQ and SQ issues in PSNs systematically. This framework should include tested dimensions and measurement items that allow us to assess IQ and SQ in practice. Accordingly, we formulated the first sub-question (1a) as:

*(RQ1a): What are tested assessment instruments provided in the literature for studying information quality and system quality in public safety networks?*

Answering the above stated question requires us to analyze literature on assessment instruments for IQ and SQ. Chapter 4 presents such assessment instruments. The second foundation we needed to establish in our knowledge base is on pathways for assuring IQ and SQ from existing kernel theories. Kernel theories

are theories from natural and social sciences governing the design requirements or the processes arriving at them. This can be either an academic and scholarly formulated set of concepts or statements, or practitioners' "theory-in-use" which is made explicit through hermeneutic process of codification (Walls, et al., 1992). A kernel theory enables to formulate testable predictions of a class of solutions and their behaviors, or the associated design process. Therefore, the knowledge base provides the clues from and through which design artifacts are constructed and evaluated. Our first hunch was that the disaster driven aggregation of heterogeneous information systems does not leverage the necessary information management capabilities for assuring IQ and SQ across a network of agencies. Instead, inter-agency and inter-echelon information management activities need to be coordinated in concert. This hunch led us to investigate literature on Coordination theory. As discussed in Chapter 3, this theory holds several pathways that could help us in synthesizing principles for assuring IQ and SQ. A pathway is a specific progression of one or more concepts in the evolution of a theory. Each pathway is a dynamic and developmental process, which may include several stages. Another theory that provides such pathways is Network Centric Operations (NCO). Stating a first hunch is quite common in design and prescription oriented research since it allows the researchers to focus, review literature more thoroughly and state expectations earlier in the research (Verschuren & Hartog, 2005). Drawing on this first hunch, we formulated question 1b as:

*(RQ1b): Which pathways do coordination theory and netcentric operations theory provide for assuring IQ and SQ in public safety networks?*

This dissertation considers *pathways* as routes or streams in theories that help scholars in purposefully navigating through the existing body of knowledge on a specific theory. As such, a pathway is a specific progression of one or more concepts in the evolution of a theory. Each pathway is a dynamic and developmental process, which may include several stages. We regarded NCO and Coordination theory as kernel theories since a preliminary analysis of both theories revealed that they do not directly provide applicable design principles for assuring IQ and SQ. Instead, we expected that these theories would provide 'pathways' that, when navigated with our empirical knowledge, would allow us to synthesize design principles.

We investigated these two sub- questions using literature review. The literature review allowed us to develop an understanding of the status of the theory on IQ, SQ, and information management, particularly in the context of disaster response. Since this dissertation aims to prescribe design principles, we also surveyed the literature for any statements of 'design', 'principles', or 'guidelines'. The literature review allowed us to reflect on the availability and capability of current state-of-the-art concepts, methods, technology, and applications that have been developed to address IQ and SQ issues in disaster response networks. We used the Scopus, Science Direct (Elsevier), IEEE, SpringerLink (Springer), ACM Portal (ACM), JSTOR and InterScience (Wiley) portals to query electronic databases from January 2007 until September 2009.

Based on the literature review, we were able to identify the dimensions and definitions of IQ and SQ. The primary key terms we used were 'coordination', 'information management', 'information quality' and 'system quality'. By analyzing literature, we started to search for (partially) useful or kernel theories that could

help us to synthesize design principles (discussed later). As we found more frameworks and dimensions for IQ and SQ, we started using these to look for in-depth studies on the individual dimensions of both constructs. In addition, we used the 'snowballing' technique to find additional papers. Chapter 3 presents the results of the rigor cycle.

## 2.5   Relevance cycle: empirical analysis using field research

Equipped with the instruments for assessing IQ and SQ, as well as theoretical pathways for assuring IQ and SQ, we started with the second cycle of this research. The main activity of the relevance cycle is empirical analysis and data collection through field studies. Scholars have suggested the use of field studies when investigating contemporary problems that lack empirical descriptions in the literature (Paul & McDaniel, 2004; Snow & Thomas, 1994). Not that a field study is a 'methodology', whereas the instruments employed for data collection are referred to as research 'methods' (Yin, 2003). In this cycle, we focus on investigation of the second research question. We divided this question in three sub-questions, each investigated with a different research method as part of the field study methodology. The research methods we employed are observations, surveys, and interviews.

### 2.5.1   Observing information management in practice: three field studies

Since literature is somewhat superficial on the design and configuration of existing information systems used in practices, the first sub-question asks:

*RQ2a: How do relief agencies in practice manage information between agencies (horizontal) and echelons (vertical) during disaster response?*

We asked ourselves this question because we wanted to gain insights in the configurations (or architectures) of existing information systems. In order to gain in depth understanding of how relief agencies manage information in practice and which IQ and SQ issues are predominant, we need to study relief workers during disaster response situations. However, investigating this research question demanded an instrument beyond literature review or case studies, especially since academic contributions on how relief agencies manage information during real disasters are scarce. The few scientific contributions available (Comfort & Kapucu, 2006; Dawes, et al., 2004) focus on a single disaster type and do not provide an in depth analysis of IQ and SQ issues. One practical reason for this may lie in the fact that it is difficult to collect empirical data during a real disaster, as the situation is unforeseen, dangerous, and researchers are not welcome near the disaster site. Moreover, multiple contexts, events, scope, control, and time related problems make it difficult to collect data in disaster field studies (Killian, 2002). Even if relief workers allowed us to study information management during real disasters, it would be difficult to plan for data collection since they would not have the time to be interviewed or surveyed. Since collecting data from real disasters was unfeasible, we decided to study relief workers during disaster training exercises. For this purpose, we decided to employ the field study approach. We studied several relief agencies during training exercises in the Netherlands. We selected the field studies based on the following criteria:

- A network of relief agencies and workers (unit of observation) as part of a safety region;
- Readiness of the organizations to cooperate and share information prior, during and after each exercise (i.e., about the scenario, participants, computer log-files etc.);
- The possibility of observation and administrating surveys amongst the participants;
- Information management during disasters situations is crucial for resolving the situation;
- There must already be some kind of information system in place at the location (no green field);

Based on the above stated field study selection criteria, we selected three field study sites in the Netherlands. Acknowledging that the number of field studies needed to capture the entire spectrum of different information system architectures in PSN is difficult to establish beforehand, we expected that three field studies would sufficiently capture some of the heterogeneity and differences in PSN. The following table outlines the main characteristics of our field studies.

| Table 2-2: Overview of explorative field studies in public safety networks | | | |
|---|---|---|---|
| | **Delfland** | **Gelderland** | **Rotterdam** |
| **Number of exercises observed** | 1 x Full day | 3 x Full day | 18 x half day exercises |
| **Focus** | Intra-agency | International, inter-agency | Interagency |
| **IT applications used during exercise** | No computer based IS, use of white-boards | Several (FLIWAS, ARCMAP, GROOVE) | Single (CEDRIC) |
| **Survey administration** | On paper, at the exercise location | On paper, at the exercise location | Web-based (invitation link via email) |
| **Number of survey respondents** | 24 (77% response rate) | 47 (90% response rate) | 83 (59% response rate) |
| **Field study period** | 2010 (1 day) | 2009 (3 days) | 2007,2008 |
| **Type of scenario** | Flooding | Flooding, chemical spills | Several types of industrial accidents |

Table 2-2 provides an overview of our field studies. Note that the Delfland field study took place in the latter stages of this research, eventually raising the question whether or not the field study is still 'explorative'. In contrast to the other field studies, we did not plan this field study at the start of this research. However, when invited to conduct this field study, we did not hesitate to do so since it was a unique opportunity to study the effects of information management using non-IT applications (whiteboards). We observed 22 training exercises, including six prior exercises observed in the winter of 2006, which we used to fine-tune our data collection instruments. The focus lies on selected IQ and SQ dimensions and information management processes, and the perspective is that of the relief worker.

Since each field study can be treated as a case study, the embedded case study design is chosen instead of a holistic case study design (Yin, 2003, pp. 42-43). Embedded case studies involve more than one unit or object of analysis (in this research, the IQ and SQ dimensions, roles, information flows and IT applications are units of analysis).Although these were training exercises, they were serious and costly activities, leaving few opportunities for interruptions (e.g., interviews during exercises). As such, before each of the field studies, we had to undertake several rounds of negotiation with the exercise organizers. It took a significant amount of talks and negotiations before trainers allowed us to study the relief workers during training exercises. The negotiation rounds were necessary to establish terms on which we studied the training exercises and what instruments we were allowed to use for data collection purposes.

In order to be able to generalize from field studies the description of the information systems has to be both comprehensive and detailed. This requires triangulation: Any finding or conclusion in a case study is likely to be more convincing and accurate if it is based on several different methods and data sources that are all used to analyze the research questions (Yin, 2003, p. 98). The instruments and data types used during the field studies include participatory observations, surveys, in-depth semi-structured interviews of key informants, internal and external documents and discussions with exercise organizers. We discuss the instruments employed during the field studies next.

### 2.5.2 Observation of information management in practice

The first data collection instrument employed for the field studies was observation. Observation is an ethnographic method that involves observing people in a natural setting over a prolonged period, and talking and listening to them (Hammersley & Atkinson, 1995). Observation was necessary because the research focused on the meanings and interpretations of exercise participants (Spradley, 1980). Without observing the information management activities of relief workers, we could not have gained understanding of the significance of information management from the perspective of the participants. Depending on the date of the training exercises and the availability of colleagues and students, the author observed the exercises together with one or two persons. Observations were conducted using a predefined observation protocol (in Appendix-B) in order to create structure in observation notes and improve inter-observer reliability through comparison. The observation protocol was extended and fine-tuned using based on the findings of the first six exercises we observed prior to the actual field studies. As we observed, we took notes and when possible, complemented these notes by taking pictures or recording specific interactions on video. We have recorded the observations of relief workers using these predefined observation protocols. Analyzing these protocols involved several iterative steps associated with grounded theory (Strauss & Corbin, 1990), including devising and attaching categories to the data in the protocols, making connections between and among categories, revising the categories, and recoding the notes.

We chose to present this material as a "realist tale," which Van Maanen defined as "[a third person] description and something of an explanation for certain specific, bounded, observed (or nearly observed) practices" (1988, p. 45). Prior to the training exercises, the exercise organizers explained our role as researchers to the participating relief workers and we agreed to disguise all individual and or-

ganizational names with pseudonyms. During our observations, we focused on three types of interactions amongst relief workers. First, we observed the face-to-face interactions between relief workers from different agencies (e.g., police, fire-fighters.). The aim was to find out which information is necessary for each team in the context of a disaster response situation, which information is exchanged during the team meetings, which software applications were used, etc. We observed the team meetings because they are the manifestations of interactions between different relief workers and thus showed several viewpoints. Second, we observed face-to-face interactions between the relief workers of the same agency. Third, we observed the information flows between a team and external information sources (such as the emergency control room). We did this by sketching data flow diagrams and by tallying information request and response during the team meetings. We counted and recorded occurrences and potential causes every time the requested information was not directly available to the team. This allowed us to get insight on the external dependencies.

### 2.5.3   Survey administration among relief workers

Observing relief workers in action provides the researcher with very rich data. This form of data collection allows the researcher to collect information on all levels of the object under investigation (the network, agency, process and individual level discussed in chapter 1). Even though the observations provided in depth insights on information management activities and flows, it remained difficult to judge the IQ and SQ experienced by relief workers. Participant observation is a poor method for generating statistical results, but its use was essential to address the topic of this study. In order to deal with this limitation, we decided to use surveys that could measure the IQ and SQ issues perceived by the participating relief workers. A survey is a means of "gathering information about the characteristics, actions, or opinions of a large group of people, referred to as a population" (Tanur, 1982, p. 295).

According to Pinsonneault & Kraemer (1993) surveys conducted for research purposes have three distinct characteristics: (1) to produce quantitative descriptions of some aspects of the study population , (2) the main way of collecting information is by asking people structured and predefined questions, (3) information is generally collected about only a fraction of the study population (a sample) but it is collected in such a way as to be able to generalize the findings to the population. There are primarily two forms of survey: (a) cross-sectional survey and (b) longitudinal survey (Rindfleisch, Malter, Ganesan, & Moorman, 2008). Cross-sectional surveys involve observation of the population or a representative subset at a defined time. In contrast, longitudinal surveys involve repeated observations of the same items over a period, often over decades. Since we wanted to measure the IQ and SQ levels resulting from the use of specific information systems during an exercised disaster scenario, cross-sectional surveys, we decided to use cross-sectional surveys. Drawing on this understanding of what a survey is, the second sub-question asks:

RQ2b: *Considering the various information system architectures in practice, which levels of IQ and SQ do these architectures assure for relief workers during disaster response?*

Asking this question is necessary for gaining insights on the impact of specific information systems have on the IQ and SQ for relief workers. IQ and SQ represent the dependent constructs of this research, whereas the information system used by relief agencies for inter-agency and inter-echelon information management is the main unit of observation on which data we collected data. Following suggestions in previous research (Lee, Strong, Kahn, & Wang, 2002), we employed both online (electronic) and paper based surveys, depending on the availability of the relief workers after the training exercises. As a result, we received 83 (59%) completed surveys from the Rotterdam case, 47 (90 %) completed surveys from the Gelderland case and 24 (77%) completed surveys from the Delfland Case. In line with expectations in the literature (e.g., Kaplowitz, Hadlock, & Levine, 2004) we experienced that the response rate to paper surveys was significantly higher than to online surveys. The results of these surveys were analyzed using descriptive statistics in SPSS 17.0. Chapter 5 presents the findings from the survey data analysis.

An important decision that we needed to make before surveying relief workers was on the selection of the appropriate IQ and SQ measures. As we discuss in sections 4.1 and 4.2, both constructs consist of a wide range of different dimensions that can be measured using one or more survey items (questions). Moreover, experts on employing statistical data analysis techniques (Field, 2005; Hair, Anderson, Tatham, & Black, 1995) suggest that each dimension or variable should be measured with at least three items in order to safeguard construct validity (three items per construct rule). While we generally prefer to adhere to this rule, we were bounded by the time we had to survey relief workers. Especially in the Gelderland and Delft field studies, trainers provided us a short period (10 minutes maximum in Gelderland and 15 minutes maximum in Delft) to survey relief workers on the spot directly after the exercise. As such, the paper based surveys needed to be short, containing a limited set of questions on IQ and SQ. In the Rotterdam field study, we had the opportunity to send out electronic surveys. The advantage of this form of surveying was that they allowed us to include a wider range of IQ and SQ variables and adhere to the three items per construct rule. Considering the trade-off that needs to be made in the number of data points and the time available to survey relief workers, the selected IQ and SQ variables were measured in three steps.

The first step was to search for IQ and SQ variables mentioned in disaster evaluation reports. The results of this first steps are outlined in tables 1-3 and 1-4 in chapter one. This set of IQ and SQ dimensions provided us with a first 'rough' sample of items for our survey. This long-list includes IQ and SQ dimensions that proved to be problematic during disaster management. The second step was to pretest the long-list in a survey with two exercise organizers and one relief worker, both related to the initial field studies in Rotterdam. In order to conduct this pretest, we first needed to translate the IQ and SQ survey items provided by Lee, Strong, Wang & Kahn (2002) from English to Dutch (see section 4.3 for the reasons we used these predefined survey items). The pre-test with the exercise organizers and the field worker was useful in three ways. First, we were able to contextualize the set of items in the survey, in order to make them easier to relate to the exercise context, roles and IT-applications. Second, the organizers and relief workers pointed out some confusing and, in their view, overlapping IQ and SQ dimensions. IQ-accuracy for instance, was a dimension they could not relate to, especially when there were also questions regarding the completeness of information. Third, the

pre-test also pointed out some semantic problems with the survey items, some of which we can attribute to the conversion from English to Dutch.

The final step we undertook to 'fine-tune' our IQ and SQ measurement instrument was to reflect on the data analysis after the first round of surveys in the Rotterdam field study in 2007. The data analysis showed that some of the questions related to the IQ and SQ dimensions were left blank, or in contrast with the previous answers. In such cases, we either reformulated the item or deleted it completely. The final set (or shortlist) of IQ and SQ measurement items used in the surveys is provided in Appendix-D.

### 2.5.4 Interviews with information architects

The investigation of the previous sub-questions would leave us with a deeper understanding of existing information system architectures and the type of IQ and SQ problems that occur when using these architecture designs. What we still missed from observing disaster response exercises and surveying relief workers was an understanding of current best practices information system architects employ for assuring IQ an SQ in practice. Moreover, we were curious on whether information system architects had already considered the pathways provided in theory (Chapter 3), albeit in a different form. As such, the final sub-question we focused on in the second cycle of this research asked:

RQ2c: *What are the existing best practices of information system architects for assuring IQ and SQ?*

This question was asked because we were convinced that IS architects not only have a better understanding of existing information systems than we have, but also that they would be the best judges of the potential pathways we found in the literature. The interviews allowed us to find out what technologies, standards and best practices the architects employ to address IQ and SQ issues in practice. In total, we interviewed sixteen information system architects. Three main criteria guided the selection process:

- The respondents needed to have at least five years of experience with designing information systems for disaster management;
- The respondents must occupy a senior position in either the development or use of information systems for multi-agency disaster management;
- Taken together, the sample should represent the main relief agencies and government departments in the Netherlands that are likely to be involved during a major disaster.

In interview studies, sample size is often justified by interviewing participants until reaching 'data saturation' (Mason, 2002). In our case, we did not expect to gain any 'new' insights after we conducted the sixteenth interview. We conducted the sixteen interviews in the second half of 2008. Respondents were interviewed in person at their office for approximately one and a half hour. Prior to the interviews, we e-mailed the objectives of this research and the type of information we were interested in (see Chapter 5) to the respondents, to ensure that all the interviews adhered to the same general format. The interviews were guided by an interview pro-

tocol containing open-ended and closed questions. The interview protocol was pre-tested through test interviews with students of the faculty of Technology, Policy and Management at Delft University of Technology in The Netherlands. During each interview, we discussed two main topics: (1) the occurrence of IQ-related problems (when necessary, led by the examples of IQ-related problems from the case surveys) and (2) ways in which architects try to overcome such problems in their design (i.e., which principles do they use).

Exploring the experiences of the architects in their particular environment made it possible to gain a richer and more comprehensive understanding of IQ problems and potential solutions. Moreover, reflecting on specific IQ-related problems together with the respondents proved conducive to a creative process of principle "shaping". The interviews were recorded on tape so as to minimize data loss. After each interview, the interview notes were first transcribed in MS Word and e-mailed to the respondents, who were asked to validate them within two weeks. In this case, validation means that the respondents checked the transcripts of the interviews for inconsistencies and determined whether the transcripts were a truthful account of the interviews or not.

Interviews were analyzed by relying on established methods for handling qualitative data (Miles & Huberman, 1994). To compare the results of the various interviews, we used the text analysis application ATLAS.ti (www.atlasti.com). ATLAS.ti is designed to offer qualitative-oriented social researchers support in their activities concerning the interpretation of text (Muhr, 1991), including the capacity to deal with large amounts of text, as well as managing annotations, concepts, and complex structures, including conceptual relationships that emerge in the process of interpretation. With linear textual data, such as transcribed interviews, as a starting point, segmentation and coding ("textual phases") of the text alternates with the building of conceptual networks and hyper textual structures ("conceptual phase").

Another important reason for using this tool is its ability to generate network views that visualize relationships among IQ and SQ variables and potential solutions. Using ATLAS.ti, the researcher can draw actual "conceptual maps" consisting of boxes and connecting lines that depict the connections between concepts in the form of as a network. Within these network views, different codes and their mutual relationships can be visualized, generating an overview of relationships between the key concepts of the interview, both individually and in combination. To establish construct validity, we matched interviewees' descriptions with the theoretical characterizations of each construct. For example, if interviewee referred to a specific information related issue as a complicating factor for multi-agency disaster response, this issue would be labeled as an IQ dimension.

The results of the relevance cycle should help us in understanding the hurdles for assuring IQ and SQ and explore the pathways identified in the previous cycle. Moreover, by observing the information management structures, roles, scenarios and issues in practice, this cycle should also help us to specify a more realistic IS evaluation approach in evaluation cycle. First, we continue by elaborating on the design cycle of this research in section 2.6.

## 2.6 Design cycle: synthesizing a design theory

The third cycle of this research draws on the findings from the previous two cycles. In this cycle, we investigated the third research question, formulated as:

RQ3: *Which design principles can we synthesize from the knowledge base and empirical data for assuring IQ and SQ during multi-agency disaster response?*

The objective here is to synthesize and specify a design theory for IQ and SQ assurance in public safety networks. Here, we need to be more specific on the structure of a design theory. Since the publication of Walls et al. (1992) the term "IS design theory" has been used in a specific sense. Design is interpreted in a broad sense, involving "solving problems, creating something new, or transforming less desirable situations to preferred situations" (Friedman, 2003, p. 507). Accordingly, design theory refers to a set of concepts, beliefs, conjectures and generalized scientific laws (both natural and social) by which designers map design problems to solutions for a special class of IS problems. These theories are aimed to give knowledge support to design activities and can be considered as theorized practical knowledge (Goldkuhl, 2004). Such bundles of knowledge encapsulate and organize three interrelated elements (Markus, Majchrzak, & Gasser, 2002): (1) a set of requirements for a family of design problems, (2) a set of methods or capabilities (drawn from integrating theory and practices) that meet these requirements, and (3) a set of principles deemed effective for guiding the design process so that a set of system features is selected and implemented that meets a given set of requirements. Table 2-3 captures the main elements of our design theory.

| Table 2-3: Elements of a design theory (after Markus et al., 2002) | |
|---|---|
| **Requirements/ goals** | A set of IQ and SQ requirements that need be assured under certain conditions and with consideration of the characteristics of public safety networks. |
| **Socio-technical system capabilities** | Measures (can be IT enabled) for achieving the set of requirements or goals. |
| **Design principles** | Knowledge (a codification of procedures) which, when applied, increase the likelihood of assuring IQ and SQ in public safety networks. These procedures are derived logically from kernel theories and empirical field studies and can be used for creating other instances of artifacts that belong to the same class. |

Gregor (2006) explains how design theory can be seen as the fifth in five classes of theory that are relevant to IS: (1) theory for analyzing, (2) theory for explaining, (3) theory for predicting, (4) theory for explaining and predicting, and (5) theory for design and action. The distinguishing attribute of theories for design (or design theory) is that they focus on "how to do something." Design theories also give prescriptions for the architecture of specific applications (i.e., information sharing applications). Moreover, a design theory provides prescriptions on how to assure a goal in practice, with the implicit expectation that the prescribed methods are "bet-

ter" than alternatives. Consequently, design theories are normative theories in the sense that they are prescriptive and evaluative, rather than solely descriptive, explanatory, or predictive (Markus, et al., 2002). We adopt a broad view of theory, congruent with Gregor (2006), which means that the term theory encompasses what might be termed elsewhere principles, guidelines, models, patterns, frameworks, or bodies of knowledge, terms that are used in connection with design science by many authors. As discussed by Walls et al. (1992), this type of theory is specifically means to provide guidance to practitioners.

The main result of the design cycle is a prescriptive design theory for inter-agency and inter-echelon information management in PSNs based on the theoretical pathways (questions 2) and the empirical findings (question 3). We denote the prescriptive design theory as *"netcentric information orchestration"* since it suggests an alternative IS architecture for information management in disaster response networks. The netcentric information orchestration framework proposes several principles that enable ISs to leverage the capabilities necessary for assuring IQ and SQ. As depicted in Figure 2-2., the design principles are synthesized from the data we collected from three sources.



**Figure 2-2: Synthesis of a design theory: principle-based design**
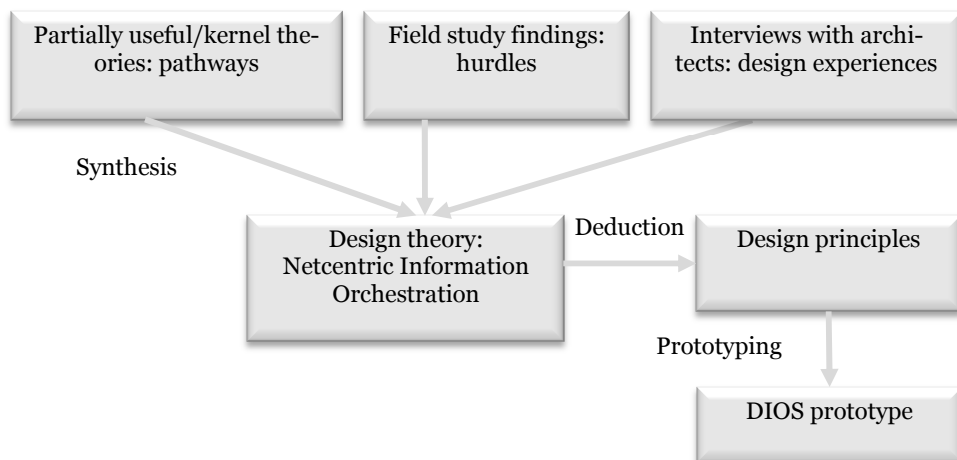
The Open Group define design principles as "general rules and guidelines, that are intended to be enduring and seldom amended, that inform and support the way in which an organization sets about fulfilling its mission" (TOGAF, 2004). Principles are particularly suited for solving ill-structured or 'complex' problems, referring to problems that cannot be formulated explicitly and quantitatively, and that cannot be solved by known and feasible computational techniques (Simon, 1996). Since principles are generic, they propose a goal driven configuration of IS architectures, without explicitly referring to (technical) solutions. Rather than suggesting a specific technical solution, principles can be translated to both organizational capabilities (i.e., adaptation to changing conditions) and technical function-

alities (i.e., simulation of events and information needs) which in turn can be translated to a prototype information system. This degree of freedom is particularly important when a designed information system is to be operated in a multi-agency network in which every agency has its own preferred standards and technologies.

Alongside the empirical data, the synthesis of principles relies on existing kernel theories that are applied, tested, modified, and extended through the experience, creativity, intuition, and problem solving capabilities of the researcher (Markus, et al., 2002). Even if the source of principles (i.e., kernel theories, experience and field study findings) is strong, the principles themselves are difficult to evaluate in a direct way. A general, domain independent reason for this is that principles are often generic and therefore difficult to falsify (Clegg, 2000).

Since principles are generic and difficult to evaluate in a direct way, we developed a prototype software system of the proposed design theory (Chapter 6). This prototype is denoted as DIOS, which is an abbreviation for Disaster Information Orchestration System. DIOS is an early version of a system that exhibits the essential features of the future operational system (in case practitioners would adopt the prototype). We need to underline that even though our design theory (in the form of principles) resides in DIOS, this prototype is a tool and not the goal of our research. DIOS is only a physical implementation of the design principles that can assist in representing the theory both as an expository tool and for purposes of testing. Accordingly, our prototype is tentative and its purpose is to demonstrate the design principles and facilitate their evaluation in a quasi-realistic setting. The DIOS box and arrow towards this box are dashed since DIOS is considered just one of the possible materializations of our design theory. Chapter 8 presents the detailed design of DIOS.

## 2.7 Evaluation cycle: prototyping and quasi-experimentation

The final cycle of this research involves an evaluation of the proposed design theory. Our prescriptive design theory must be evaluated with respect to the utility for relief workers when it comes to assuring IQ and SQ. Evaluation is an assessment process, which enables the design science researcher to understand the problem addressed by the artifact and the feasibility of the approach for its solution (Nunamaker Jr, Chen, & Purdin, 1990). Accordingly, we formulated the fourth and final research question of this dissertation as:

RQ4: *to what extent do the proposed design principles assure higher levels of IQ and SQ for relief workers when compared to information systems in practice?*

Following Twidale et al. (1994), we view evaluation as an assessment of whether the principles embodied in the prototype have been proved to be superior to an alternative, where that alternative is frequently the current approach to information management in PSNs. There are several methodologies for evaluating an artifact (Verschuren & Hartog, 2005). We choose the use a prototype for this purpose. Evaluating any solution for problems during a real disaster is difficult since the prototype, if not functioning correctly, may seriously harm relief operations. We first considered the use of computer based simulation models, an approach frequently employed for theory evaluation purposes (see for instance Gonzalez, 2010). Simulation involves creating a computational representation of the underlying theoretical logic that links constructs together within these simplified settings. Schol-

ars than code these representations into software that they run repeatedly under varying experimental conditions (e.g., alternative assumptions, varied construct values) in order to obtain results. While the use of computer simulation has some advantages (i.e., low cost, easy to build and replicated runs), there are some major concerns when using simulation. Davis et al. (2007) for instance sum up several limitations of simulation, suggesting that simulations are "toy models of actual phenomena, in that they either replicate the obvious or strip away so much realism that they are simply too inaccurate to yield valid theoretical insights" (p.480). Computer based simulation models are unable to capture the complex social and behavioral interactions that affect information management in practice. Moreover, simulations either require a vast amount of empirical data or theoretically rendered data on IQ, SQ and information management (e.g., frequency of occurrences, durations etc.). As stated in the previous sections, this type of data is difficult to obtain.

Based on these limitations, we opt for evaluating the proposed prototype resulting from the design cycle using a quasi-experimental gaming-simulation. We consider the quasi-experimental gaming-simulation as part of our design science research approach. In this way, we could re-use some of the data collection instruments developed for the field studies, including the observation protocols and survey. Moreover, we employed the experience gained from observing several disaster response exercises in the relevance cycle for developing an evaluation session that resembled the training exercises familiar to the professional relief workers. In this way, we reduced the time needed to prepare professionals for the gaming-simulation. Before discussing our quasi-experimental gaming-simulation, we first discuss the series of pre-tests we conducted in order to fine-tune our design.

### 2.7.1 Series of pre-tests

Although the prototype was complete in the sense that it provided specific functionalities that we deemed necessary for IQ and SQ assurance, we still needed to pre-test the prototype before we could actually evaluate the underlying principles with professional relief workers. We considered the first series of pre-tests as less authentic testing activities meant to eliminate gross system errors in a more economical manner. If those errors remain until the actual gaming-simulation, not only will the delay mean that the errors are more difficult (and costly) to rectify, but the gross errors will completely swamp the interaction, making it unlikely that more subtle but still significant system errors will be observed at all, as shown in Figure 2-3.

As illustrated in figure 2-3, our approach to evaluating DIOS includes to three pre-tests. Note that the lines indicating the number of errors and omissions in the prototype are neither accurate nor quantifiable, they just represent our expectations of finding fewer errors as the evaluation rounds progressed. The first series of pre-tests the application developers (author and two graduate students) undertook authentic tasks such as information collection and rating using the DIOS prototype. The user interface design was still fluid as the functionality was the main object of testing. This series of pre-testing revealed some problems, including a lack of functionality, which were rectified. The second series of pre-testing involved end-users increasingly remote from the development group, including project members not involved in systems development, graduate computing students, and undergraduates with less computer experience. The advantage of this approach is that it does not take a large number of subjects to reveal problems with a develop-

ing system, and so one can discover what is wrong quickly and cheaply. The major activities here include functionality, interface (presentation tier) and stress testing (performance).

**Figure 2-3: Stages and scope of the prototype pretest sessions**

# Errors & omissions in the prototype (Discussed in chapter

1) Simple test cases by developers

2) More complex test cases by colleagues

3) Advanced test cases by students

Time and number of testers

The final series of pre-testing included a testing sessions with a group of 24 graduate students. Here, we wanted to pre-test the prototype in an environment of users similar to the one relief workers operate in. This means that we tested all tiers of the prototype (presentation, application logic and data). The group of under-graduate students was divided in four teams, similar to a disaster response net-work. We provided each student with a specific role and set of tasks, similar to the ones we observed during the field studies (see Chapter 4). While prototype testing was one of the main objectives of the pretest with graduate students, this session also allowed us to test our preliminary gaming-simulation design. We discuss the gaming-simulation design next.

## 2.7.2 A quasi-experimental gaming-simulation

Following the dialectical relation between the "context of discovery" and the "con-text of justification" (Kuhn, 1970), we argue that theory should be both generated from empirical data and tested against empirical data. For empirically evaluating our proposed design theory, we developed and employed a quasi-experimental gaming- simulation. Gaming-simulations present participants with a setting that generates real-life experiences. Using this instrument, we "recreated" two disaster situations, one per round of gaming, according to a quasi-experimental setup. In

this way, each round resembled the training exercises we observed during our field studies. This chapter is limited to explaining our motivation for employing these instruments and discusses their strengths and weaknesses. We present the specific content and process of gaming-simulation in Chapter 8.

### 2.7.3   Gaming-simulation for evaluation purposes

Duke and Geurts (2004) define a gaming-simulation as "a special type of model (that uses gaming techniques to model and simulate a system. A gaming-simulation is an operating model of a real-life system in which actors in roles partially recreate the behavior of the system" (p.36). Gaming-simulations are a simplification and condensation of a real system, allowing real participants to experiment safely with (future) information system designs, and reflect on the outcomes whatever type of simulation is used (Meijer, Hofstede, Omta, & Beers, 2008). Often, the distinction between simulations and games is blurred and the two terms are often used interchangeably (Kleiboer, 1997). According to Greenblatt (1988), games reflect players characteristics (goals, activities, constraints on what can be done and payoffs) and player decisions are important. As discussed by Klabbers (2008), games are often used for explaining the future. Games are usually intended to let the individual participants gain certain insights and skills, within or outside a specific context. Systematic feedback to participants is a crucial aspect of gaming, especially when they are used for teaching, training, and planning purposes. Simulations, on the other hand, are operating models reflecting the core features of a real or proposed system, process or environment (Greenblatt, 1988). Simulation can be defined as "a conscious endeavor to reproduce the central characteristics of a system in order to understand, experiment with and/or predict the behavior of that system" (Duke, 1980, p. 23). Hence, simulations can entail virtual participants, since they are intended to generate output values related to different choices. Gaming, however, always entails real participants (Ibid.).

Kleiboer (1997) mentions that two types of distinctions are relevant when designing simulations for research in the domain of disaster management. The first distinction involves the research objectives for which simulations are used. Researchers can use simulations for theory development or for more practical, applied problem solving. The second distinction concerns the methodological strategy. Here, simulations in which researchers explore phenomena in order to arrive at potentially relevant hypotheses (exploratory simulations) should be distinguished from simulations designed to test existing hypotheses (testing simulations). In these types of simulations, analysts attempt to probe aspects of crises by simulating them under controlled conditions in a laboratory. By systematically holding some conditions constant and manipulating others in successive runs of a simulation, the analyst can observe and measure the assumed relationship between selected variables. Based on above stated characteristics of games and simulations we can conclude that not all simulations are games and not all games are simulations, in the sense that they are not necessarily designed to epitomize part of the real world.

Previous research on disaster information systems has already used gaming-simulation. For example, Kraus et al. (1992) have developed the so-called Hostage Crisis Simulation to test hypotheses in crisis decision making. Their ultimate objective was the creation of a prototype of an automated negotiator based on a strategic model of negotiations. Over the years, gaming-simulations have taken different forms, yielding various blends of human actors and software applications.

Starting from a baseline scenario (t = 0), gaming-simulations confront participants with a series of inter-related sequences including developments and problems that require decisions and actions on their part at times t = 1, t = 2, . . . t = n. These occasions for decision are fed to participants by the controllers (researchers) of the gaming-simulations according to a more or less fixed script. Each new input into the gaming-simulation serves a particular purpose and were the focal points for observations, analysis and post-exercise feedback on the part of the controllers. The participants in gaming-simulations are usually enacting roles. As a group, they may be called upon to place themselves in the position of an individual or team operating in the given disaster context. The elements of a gaming-simulation (i.e., roles, rules, objectives and constraints) are used to define the structure of the gaming-simulation itself. The following figure illustrates the main elements of a gaming-simulation design.



**Figure 2-4: Gaming-simulation framework (based on Meijer, 2009)**
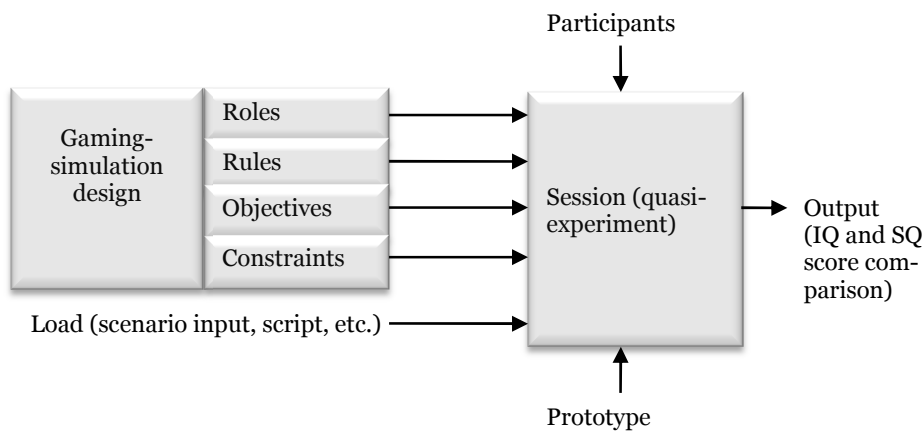
The roles in a gaming-simulation include roles for participants and roles for game facilitators. Apart from these elements, there are also specific session elements, i.e. load and situation. Loads can be defined as the values of all variables in the design of the gaming-simulation (Meijer, 2009). The inputs are known and can be controlled. The uncontrolled variable is the group of participants, but their selection can be structured. Rules in a gaming-simulation can limit the behavior of participants in order to control the environment. In addition, rules shape the behavior as they define what is allowed or forbidden during the gaming-simulation. The load of a gaming-simulation includes the scenario, process script and "starting values" for a session. We discuss these elements in detail in Chapter 8.

### 2.7.4   Addressing pitfalls in gaming-simulation

In hindsight, there were four pitfalls that could influence the outcomes and need to be circumvented. First, simulations based on scenarios always differ from reality. Real disaster situations pose more problems and dilemmas than a simulation designer can imagine. Consequently, gaming-simulations cannot fully reenact

the dramatics of real life-or-death decisions. In other words, the distinction between major and minor issues is therefore always a bit more difficult to detect in simulations. By mimicking the observed training exercises, we attempted to reduce the gap with real disaster as much as possible.

The second pitfall of gaming-simulations is that they follow fixed or predetermined scenarios. From the very beginning, it is clear that the situation will escalate no matter what participants decide. An overload of pre-formulated messages and pre-designed interventions by the simulation staff almost guarantees that the participants will act and decide in accordance with the preconceived outcome of the scenario. When doing so, participants cannot in any way affect the final outcome, maybe even leaving them to belief that their efforts are a total waste of time. This rigidity in format can easily undermine the success of the simulation, as participants begin to act in a resigned or lethargic manner as yet another disaster is imposed on them. We circumvented this pitfall by continuously monitoring the flow of the game and the motivation of the participants. Whenever necessary, less messages and events were simulated and distributed, even when this meant that the disaster scenario would not fully mature.

The third pitfall is getting a valid set of relief workers to 'voluntarily' participate in a time consuming gaming-simulation. While we had established a good relation with the exercise organizers from our field studies, dedicating one of their training exercises for our evaluation purposes was 'too much to asks'. Not only were the planned training exercises very costly, they were also deemed too important in terms of training disaster response protocols. After a number of 'orientating' talks with trainers, we have concluded that we needed to emphasize 'the what's in it for me' part of our gaming-simulation, me referring to the relief worker. Accordingly, we circumvented this pitfall by actively soliciting in PSNs and advertising the advantages of participating in our gaming-simulation. Looking back, the old saying by Confucius, 450 B.C: "Tell me, and I will forget. Show me, and I may remember. Involve me, and I will understand" really helped us in getting people existed to participate in the gaming-simulation. In the end this helped us to gain a half day slot in a training class for relief workers, yielding a perfect sample of participants.

The final pitfall is the lack of control of the preferences and motivation of selected participants. In contrast to more controlled evaluation approaches, gaming-simulation requires broad and active stakeholder involvement. The use of such a participant dependent approach and the adoption of users' satisfaction as a key evaluative measure may question the hypothesis that there exists a strong relationship between participants' satisfaction and system effectiveness. Consequently, a good IS design perceived as poor by the participants becomes a poor design. If the purpose of the game is to reach general conclusions rather than to train people, then human participation may even create much noise. For instance, a player can show inferior performance not because he is supplied with poor information but because he lacks the feeling of being involved, gets bored, is confronted with superior opponents, etc. We circumvented this pitfall in two ways. First, we tried not to make the gaming rounds too long, in order to avoid people getting bored. Second, we stated at the start of the exercise that the observers would also act as judges and that the most active players in each team would win a small prize (a chocolate bar), hoping this would at least trigger participant to compete. These measures worked to some extent, especially the prizes created some smiles. Yet, we were unable to fully avoid everyone from getting bored or annoyed during our gaming-simulation.

Two participants were very critical about the game, and what was in it for them. They also did not put much effort in completing the surveys. Still, we kept requesting them to finish the quasi-experiment and promised the feedback session at the end of the game would discuss some important principles that they may benefit from in practice.

### 2.7.5 Quasi-experimental configuration

Since the final research question asked to compare the levels of IQ and SQ assured by an information system based on netcentric information orchestration versus information systems in practice, we designed the gaming-simulation as a quasi-experiment. This means that we divided the game in two comparable rounds: one without the design principles and one that included them. Campbell and Stanley consider an experiment as "that portion in research in which variables are manipulated and their effects upon other variables are observed" (Campbell & Stanley, 1969, p. 2). In other words, an experiment can be used to determine cause and affect relationships between variables. The common attribute to all experiments is control of treatment. Experiments require (1) variation in treatment, (2) post-treatment measures of outcomes, (3) at least one unit on which observation is made, and (4) a mechanism for inferring what the outcome would have been without treatment (counterfactual inference) (Shadish, Cook, & Cambell, 2002).

The design of experiments is usually in line with the goal of finding whether one operationalization of a construct (an independent variable) causes a change in another operationalization of a construct (a dependent variable)—holding everything else constant. There are two types of experiments a researcher can choose to test cause and effect relationships: (1) natural or true experiments and (2) quasi-experiments. A true experiment is characterized by the following aspects: more than one purposively created group, common measured outcome(s), and random assignment (Gribbons & Herman, 1997). True experiments do have some drawbacks: they are often expensive, time-consuming and in several cases not doable because it is nearly impossible to fully control all important variables that could influence the experiment (Gribbons & Herman, 1997). These restrictions also apply for the current study. Moreover, full control over all variables that could influence a disaster would reduce the level of realism the current study strives for in the evaluation cycle. Moreover, since comparison was the main objective of the evaluation cycle, a quasi-experimental configuration of the gaming-simulation was preferred.

Though not strictly true experiments, quasi-experiments are explanatory designs that can provide valid and reliable evidence about the relative effectiveness of an intervention compared with another intervention or no intervention. Quasi-experimental methods are useful when you do not have the capacity to apply random assignment, or when doing so would be unethical. The use of quasi-experiments is an attempt to ensure that the right conditions are available to allow researchers to infer a presumed causal relationship between independent and dependent variables. The conditions are (Campbell & Stanley, 1963):

- The causal factor occurs before the observed effects
- The causal factor co-varies with, or is related to, the observed effect
- Alternative explanations for the observed effect have been ruled out

In quasi-experiments, the cause is manipulated and occurs before the effect is measured. This differs from a true experiment because in true experiments the cause cannot be manipulated. Since we needed to evaluate the design principles embodied in our prototype, we needed to be able to manipulate the cause (e.g., information collection capabilities, roles, tasks, flows between echelons.) prior to measuring the effects of this interventions. Hence, quasi-experimentation was a more suitable option for this research. By definition, quasi-experiments lack random assignment. Assignment to conditions is by means of self-selection, by which units can choose treatments for themselves or by means of administrator selection who decides which unit should get which treatment. The researcher has to enumerate alternative explanations one by one, decide which are plausible and then use logic, design and measurement to assess whether each one is operating in a way that might explain any observed effect. The strength of experimentation is its ability to illuminate causal inference (Shadish, et al., 2002). Compared to true-experiments, the weakness of quasi-experimentation is doubt about the extent to which the causal relationship can be generalized creating less compelling support for counterfactual inference (Ibid.).

The quasi-experimental design has several possible variations, each with their own strengths and weaknesses (Campbell & Stanley, 1963). One distinction is whether there are one or two groups of participants. The field studies made us aware of the difficulties of getting relief workers to participate in research initiatives. Since we wanted to include at least two disaster response echelons (strategic and tactical) consisting of relief workers from the main relief agencies (police, fire department and ambulance services), we needed between 20 and 30 relief workers for the gaming-simulation (see explanation in Chapter 8). In order to make it interesting for relief workers to participate, the gaming-simulation should also provide some value for them. In contrast to double group quasi-experiments, single group experiments allow participants to learn because participants experience sessions with and without treatments. As such, we selected a single group design. A second distinction is how often measurements are taken and when (prior to or after interventions). Since our goal was to evaluate the effects of the design principles on IQ and SQ, we needed a pre-treatment measurement and a post-treatment measurement (posttest). Therefore, we decided to conduct a single group pretest-posttest quasi-experiment. Figure 2-5 illustrates the configuration of the quasi-experiment.

**Figure 2-5: Quasi-experimental configuration**

| Single group pretest-posttest quasi experiment | | | G= Group of relief workers |
|---|---|---|---|

G $\qquad$ O$_1$ $\qquad$ G $\qquad$ X $\qquad$ O$_2$ — with "Round 1" below the first segment and "Round 2" below the second segment, and legend: G= Group of relief workers; X=Experiment change/treatment; O=Observation.
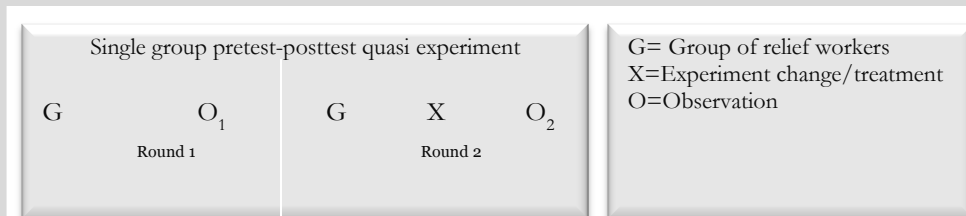
As illustrated in figure 2-5, each quasi-experimental gaming-simulation consisted of two rounds. The treatment, in this case information management

based on the design principles of netcentric information orchestration, was only provided in the second round of the gaming-simulation (see Chapter 8). We conducted toe quasi-experiments, one with master students and one with professionals. The quasi-experiment with master students functioned as a proof of concept, allowing us to test both the design of our gaming-simulation (e.g., the role descriptions and scenario's) and the prototype allowing for netcentric information orchestration (see Chapter 7).

During the session with the professionals, the participants were non-randomly assigned because they are invited to play in their own role (the role they fulfill in practice) in order to capitalize the practical expertise the participants have. We opted for this because we wanted to mimic the conditions of a real disaster as much as possible. We conducted our gaming-simulation with a group of 24 professional relief workers. The main reason for this number is that we want to mimic the real life PSN as much as possible, and for this, we needed at least 20 different roles spanning three main disaster relief organizations (police, fire department and ambulance services). After each round, we requested participants to fill in surveys regarding IQ and SQ measures. Appendix-D presents the survey questions. We recorded both sessions on video such that we could trace missing information afterwards. Each session took approximately 4 hours. Finally, we used observational data and video recordings to corroborate the survey data, as part of the evaluation methodology, and data analysis in an effort to provide triangulation of the data and therefore minimize threats to validity, an issue we elaborate on next.

## 2.7.6    Validity of the evaluation instrument

As for any type of academic research, validity of the research approach is a key issue. Regarding the validity of the research instrument, three types of validity need to be addressed: psychological, structural and process validity (Peters, Vissers, & Heijne, 1998). The *psychological validity* refers to the degree that the gaming-simulation provided an environment that seems realistic to the participants. In our session with professional relief workers, the participants were from different geographical regions and relief agencies, and had different levels of experience with disaster response. Consequently, it was difficult to assure a high level of realism across such a heterogeneous group of participants. We tried to deal with this issue by using as much materials from actual disasters as possible. For instance, we used video footage from relief agencies traveling to a real disaster in order to generate a common feeling of urgency. Since the game was conducted in a gaming-simulation suite of the Police Academy, we were also able to tweak variables such as room temperature, lighting and sound in order to proximate real disaster situational conditions. Since we expected that the contingency factors, referring to the complexity, dynamics and uncertainty of the scenarios used could act as disturbing factors, we kept these factors constant by using comparable scenarios.

*Structural validity* refers to the degree that the structure of the gaming-simulation (the theory and assumptions on which it draws) was isomorphic to that of the reference system (i.e., a PSN in practice). The structure of our gaming-simulation was in accordance with the coordination structure for multi-agency disaster response (see Chapter 4) and the training exercises we observed during the field studies. This structure dictates the way in which relief agencies collaborate in a predefined authority structure. The main advantage of structuring the gaming-simulation in accordance to the GRIP authority structure (see Chapter 4) was that

the relief workers were familiar with this structure, reducing the time we needed to introduce the gaming-simulation.

*Process validity* refers to the degree that the processes observed in the gaming-simulation were isomorphic to those observed in the reference system. Assuring process validity in disaster response is difficult, if not impossible. Relief workers often act and decide in reaction to the hazards and events facing them and not in accordance to a predictable set of processes. The high level of unpredictability surrounding events and decisions makes it hard to predefine the exact flow of disaster responses matching with our quasi-experimentation.

### 2.7.7    Generalizability of research findings

The generalization or external validity refers to what extend the findings from this study can be generalized and transferred to other cases or agencies in other domains and settings. Cook and Campbell (p.39, 1979) define external validity as "approximate validity with which conclusions are drawn about the generalizability of a causal relationship to and across populations or persons, settings, and times". One can find several definitions and conceptions of generalizability in information systems research. The Oxford English Dictionary defines to generalize as "to form general notions by abstraction from particular instances," generalizable as "capable of being generalized," and generalizability as "the fact or quality of being generalizable." Conceptualized in this way, generalizability need not have a quantitative or statistical dimension. This is in contrast to the positivistic research that generalizes based on statistical power. In contrast, the philosophical tradition of interpretivism places no particular emphasis on generalizability or the striving for universally applicable theories. In interpretivism, a theory is only relevant to the setting where it was developed (i.e., the Netherlands) would not detract from its validity or scientific status. At the same time, interpretivism would not prohibit the researcher from extending his or her theory to additional settings.

Usually, generalization involves extrapolation into a domain or setting not represented in one's sample (Campbell & Stanley, 1969). Such extrapolation is made by assuming one knows the relevant conditions. We did not attempt generalization by guessing at laws and checking out some of these generalizations in other equally specific but different conditions. Moreover, every solution to a wicked problem is a "one-shot operation", because there is little opportunity to learn by trial and error, every attempt counts significantly. In this research, we collected empirical data from three field studies and tested our design theory with professionals. The gathering of additional data can indeed be beneficial to the reliability of our study.

However, as pointed out by Lee & Baskerville (2003) this is distinct from any increase in the generalizability of a sample to its population. An increase in sample size is beneficial, but the benefits take the form of improved reliability of the sampling procedure, rather than improved generalizability of a sample to its population. Reliability refers to the extent to which the same or a different researcher can, at least in principle, reapply the same procedure when making another observation or measurement (e.g., observing the average of another random sample of the same size taken from the same population) and expect it to lead to the same result as before (Ibid.). We agree with Lee & Baskerville (2003) that a theory may never be generalized to a setting where it has not yet been empirically tested and confirmed. Nevertheless, we strived to maximize the opportunities to

transfer the findings (i.e., principles) from our study directly to the real world, realizing that our artificial gaming-simulation and the real situation are all but unequivocal. Along the same lines, neither an increase in the sample size in a statistical study nor an increase in the number of field studies or gaming-simulations would be an indicator of greater generalizability of a theory to new settings.

## 2.8   Summary

This chapter elaborated on the philosophy and methodological approach that guided us throughout the research project. We explained why we chose to employ the design science research approach. Based on the research objective (*synthesize and evaluate information system design principles that assure higher levels of information and system quality for relief workers during multi-agency disaster response),* this chapter introduced four research questions. Following the design science research approach, our research consisted of four cycles: (1) a rigor cycle, (2) a relevance cycle, (3) a design cycle and (4) a evaluation cycle. Each of these cycles focuses on answering a different research question. In addition, each cycle required us to employ different research instruments, including literature analysis, observations, surveys, interviews, prototyping and gaming. Chapter 3 proceeds by presenting the results of the rigor cycle, the theoretical foundation, of this research.

# 3 Knowledge base: kernel theories for assuring IQ and SQ

*"Even for practical purposes theory generally turns out the most important thing in the end".*

Sir Oliver Wendell Holmes, American professor (1809-1894)

## 3.1 Introduction

This thesis aims to contribute design principles that assure higher information quality (IQ) and system quality (SQ) for relief workers in public safety networks (PSNs). As one of the foundation needed for achieving this goal, this chapter covers the first two research questions of this study: (RQ1a): *What is a useful and tested framework provided in the literature for studying information quality and system quality in public safety networks?* In addition (RQ1b): *What pathways do coordination theory and netcentric operations theory provide for assuring IQ and SQ in public safety networks?*

Investigating these two questions draws heavily on existing literature and results in the knowledge base of this research. As discussed in chapter two, establishing a knowledge base is a critical stage when conducting design science research. The result of investigating the first question is in a coherent framework describing the various dimensions of IQ and SQ and provides an accompanying assessment instrument for measuring IQ and SQ. We view both information and information system related problems as symptoms of the underlying information system architectures used in PSNs. Since defining and testing measures for IQ and SQ are not part of our research objective, we decided to employ well defined and tested (i.e., on construct validity) constructs provided in the literature. The resulting assessment instrument is a prerequisite for empirical data collection (Chapter 4).

Investigating the second question leads to the 'state of the art' concepts and pathways for assuring IQ and SQ. As we have explained in chapter 1, a pathway is a specific progression of one or more concepts in the evolution of a theory. Each pathway is a dynamic and developmental process, which may include several stages. The resulting pathways help us to understand the limitations in existing information system architectures and identify opportunities (i.e., design principles) for assuring IQ and SQ (chapter 6).

This chapter elaborates on some frameworks for studying IQ and SQ, followed by some pathways from Coordination theory and Network Centric operations than can lead to principles for assuring IQ and SQ. Parts of this chapter were published in the proceedings of the Sixth ISCRAM conference (Bharosa, Van Zanten, Zuurmond, & Appelman, 2009) and the Decision Support Systems Journal (Lee, Bharosa, Yang, Janssen, & Rao, 2010).

## *3.2   Information Quality*

### 3.2.1   Distinguishing information from data and knowledge

Before we can measure IQ, we first need to specify our definition of information and how information differs from data and knowledge. Previous studies dealing with information quality (see for example, Strong et al., 1997) and more recent studies such as the book by Wang et al. (2005), use information quality (IQ) and data quality (DQ) interchangeably. Moreover, numerous disaster evaluation studies (e.g.,Commission, 2002; Samarajiva, 2005; Townsend et al, 2006) mix up problems regarding data, information, knowledge and intelligence in their analysis. In order to avoid conceptual confusion, it is necessary to define information, especially in relation to data and knowledge. Attempts to define these concepts are numerous and produced slightly different results, depending on which discipline is looking at them. Many of the contributions in the knowledge management area propose a data–information–knowledge hierarchy to explain the nature of knowledge (see Daft, 2001; Davenport  & Prusak, 1998; Ramesh & Tiwana, 1999). Meadow et al. (2000) refer to data as a "string of elementary symbols, such as digits or letters" (p.35). Whereas data designates 'raw,' unconnected, quantitative or qualitative items, the term information relates to answers to questions or statements about situations or facts (Eppler, 2006). Data in this sense becomes information when it we relate it to other data or data that we have organized in a manner that gives them meaning for the recipient. Wiig (1999) defines information as "facts and data organized to characterize a particular situation and knowledge as a set of truths and beliefs, perspectives and concepts, judgments and expectations, methodologies and know-how" (p.3). Therefore, information can be seen as data made meaningful by being put into a context, while knowledge can be seen as data made meaningful through a set of beliefs about the causal relationships between actions and their probable consequences, gained through either inference or experience (Mitchell, 2000).

Ramesh and Tiwana (1999) stipulate that knowledge is actionable information. We interpret this as stating that knowledge is a special type of information, which endows agencies with the capability to perform actions. Davenport and Prusak (1998) add that knowledge is information constructed by an agency – by abstraction, deduction, induction or abduction. As such, knowledge differs from information in that it is predictive and can be used to guide action while information merely is data in context. For example, if the is thermometer outside shows 2 degrees centigrade (raw data), then information would be it is 2 degrees centigrade outside, and knowledge would be that 2 degrees centigrade is cold and one must dress warmly. In other words, knowledge is closer to action, while information is a documentation of pieces of knowledge. In the context of this research, we look at information as potential knowledge. Drawing on the definitions of the previously cited scholars, we view information as data presented in a form that is useful for multi-agency teams during disaster response. Information is valuable for the relief worker when it reduces uncertainty and increases knowledge about a particular area of concern (e.g., hazards, equipment, emergency personnel etc.). According to this view, data are facts or figures in raw form that are unprocessed by the information system and in most cases are the result of the data gathering stage in the information management cycle. Data represent the measurements or observations of objects and events. To become useful to a relief worker, information sys-

tems must process and transform data into information, meaning that the remaining stages of the information management cycle (i.e., preparation, interpretation, enrichment) are completed at least once. The most basic function of an information system, then, is to transform data into information that is useful in decision-making. So we come to the question: what attributes give information its utility value? We discuss some of these attributes or 'dimensions' of information next.

### 3.2.2    Definitions and frameworks for information quality

Since the late 1990's, scholars considered data- and information quality assurance as major challenges in information systems research. In their theory on Information Systems Success, Delone and Mclean (1992) even included the IQ construct as one of the antecedents for the successful use and adoption of information systems in organizations.

Evans and Lindsay (2005) stress that quality can be a confusing concept. They provide two main reasons for this assertion: (1) people view quality using different perspectives and dimensions based on their individual roles, and (2) the meaning of quality continues to evolve as the quality profession grows and matures. Similar to product quality, IQ has no universal definition. Nevertheless, several scholars have attempted to define what IQ means, resulting in definitions such as:

- IQ is a *set of dimensions* describing the quality of the information produced by the information system (Delone & Mclean, 1992).

- Quality of information can be defined as *a difference between the required information* (*determined by a goal) and the obtained information* (Gerkes, 1997)

- IQ is the characteristic of information to meet the *functional*, *technical*, *cognitive*, and *aesthetic* requirements of information *producers*, *administrators*, *consumers,* and *experts* (Eppler, 2003)

- Information of high IQ is *fit for use* by information consumers (Huang, Lee, Wang, 1999, p. 43)

This list of definitions is not exhaustive, several other definitions may exist in the literature. Instead of elaborating on the several possible definitions for IQ, we found that scholars often substantiate their conceptualization with a set of criteria (or dimensions) quality information should meet. These criteria can be used as a benchmark to improve the effectiveness of information systems and to develop IQ strategies (Miller, 1996). Table 3-1 provides an overview of IQ frameworks, including some criteria or dimensions for conceptualizing IQ.

**Table 3-1: Some frameworks for conceptualizing IQ in the literature**

| Scholars | Model of IQ | Constructs | |
|---|---|---|---|
| (Strong, Lee & Wang, 1997) | A Conceptual Framework for Data Quality Elements: » 4 Categories » 16 Dimensions | *Category* | *IQ dimension* |
| | | Intrinsic IQ | Accuracy, Objectivity, Believability, Reputation |
| | | Accessibility IQ | Accessibility, Security, Relevancy, Value-Added, Timeliness, |
| | | Contextual IQ | Completeness, Amount of Info, Interpretability, Ease of Understanding, |
| | | Representational IQ | Concise Representation, Consistent Representation |
| (Zhu & Gauch, 2000) | Quality metrics for information retrieval on the WWW Summary: » 6 Quality Metrics | *Assessment class* | *IQ Criterion* |
| | | Currency | Measured as the time stamp of the last modification of the document |
| | | Availability | Calculated as the number of broken links on a page divided by the total numbers of links it contains. |
| | | Information-to-Noise-Ratio | Computed as the total length of the tokens after preprocessing divided by the size of the document |
| | | Authority | Based on the Yahoo Internet Life (YIL) reviews, which assigns a score ranging from 2 to 4 to a reviewed site |
| | | Popularity | Number of links pointing to a Web page |
| | | Cohesiveness | Determined by how closely related the major topics in the Web page are |
| (Naumann & Rolker, 2000) | Classification of IQ metadata criteria elements: » 3 Assessment Classes » 22 IQ Criterion | *Assessment class* | *IQ Criterion* |
| | | Subject Criteria | Believability, Concise representation, Interpretability, Relevancy, Reputation, Understandability, Value-Added |
| | | Object Criteria | Completeness, Customer Support, Documentation, Objectivity, Price, Reliability, Security, Timeliness, Verifiability |
| | | Process Criteria | Accuracy, Amount of Data, Availability, Consistent representation, Latency, Response Time |

Table 3-1 outlines three different frameworks for investigating the quality of information. We included these frameworks in the table because of their level of detail compared to other frameworks. Each of the selected frameworks suggests taking a different perspective on information as input or output of an information system. One of the things we can conclude from this table is that IQ is a multidimensional construct. This means that we need to assess the quality of information based on multiple attributes or dimensions. Several researchers have attempted to identify the dimensions of IQ. For instance, Wang et al. (1995) list 26 IQ dimensions, which in turn are classified into either internal view (design operation) or external view (use and value). Wang and Strong (1996) conducted an empirical two-phase sorting study and have provided the most comprehensive list of IQ attributes. Their initial list includes 118 attributes. These 118 attributes were later reduced to 20 dimensions, which in turn are grouped into four categories: accuracy, relevancy, representation, and accessibility. Later, Strong, Lee & Wang (1997) re-examine their four initial categories and re-labeled the first two categories and the four categories to become: intrinsic, contextual, representation, and accessibility.

1. Intrinsic information quality means the information has quality in its own right.

2. Contextual information quality refers to the fact that information is used to perform a task and that information has to be relevant, timely, complete, and appropriate in order to add value.

3. Representational information quality means the information must be readable, understandable, and clear in order to be useful.

4. Accessibility information quality refers to information systems that store and provide access to information.

While IQ as the quality of the information product implies data quality (DQ) or the quality of its raw material data, the reverse is not always true. Good IQ implies good DQ and poor DQ causes poor IQ. However, a good DQ may not necessarily lead to good IQ. Errors within the processes of transforming data into information can lead to poor IQ. A researcher or analyst may collect accurate, complete and timely data but may conclude from them poor quality information. Having elaborated on our view of IQ, we proceed with discussing instruments for assessing IQ in the next section.

### 3.2.3   Measuring Information Quality

The framework proposed by Strong et al. (1997) is the only framework that is evolved and refined over the years and proposes empirically tested items for IQ measurement (see Lee, et al., 2002). This is the main reason for adopting this framework for studying IQ issues in PSNs. The following table outlines the various measurement items for the IQ dimensions proposed by Lee et al. (2002).

**Table 3-2: IQ categories, dimensions, and measures (Lee et al. 2002)**

| Category | Dimension | Measurement items |
|---|---|---|
| Intrinsic IQ | Accuracy | The extent to which information represents the underlying reality |
| | Objectivity | The extent to which information is unbiased, unprejudiced, and impartial |
| | Believability | The extent to which information is regarded as true and credible |
| | Reputation | The extent to which information is highly regarded in terms of its source or content |
| Accessibility IQ | Accessibility | The extent to which information is available, or easily and quickly retrievable |
| | Access Security | The extent to which access to information is restricted appropriately to maintain its security |
| Contextual IQ | Relevancy | The extent to which information is applicable and helpful for task execution |
| | Value added | The extent to which information is beneficial and provides advantages from its use |
| | Timeliness | The extent to which information is sufficiently up to date for task execution |
| | Completeness | The extent to which information is not missing and is of sufficient breadth and depth for task execution |
| | Appropriate amount of data | The extent to which the volume information is appropriate for task execution |
| Representational IQ | Interpretability | The extent to which information is appropriate languages, symbols and units and the definitions are clear |
| | Concise representation | The extent to which information is composedly represented |
| | Consistent representation | The extent to which information is presented in the same format |
| | Understandability | The extent to which information is easy comprehended |

Table 3-2 lists fifteen different dimensions of IQ and provides metrics for measuring the dimensions. Individuals have different ways of considering the quality of information as they have different wants and needs and, hence, different quality standards which lead to a user-based quality perspective (Evans & Lindsey, 2005). This perspective is consistent with the Juran definition of quality which defines quality as "fitness for intended use" (Juran & Godfrey, 1999, p. 22). Thus, information is of high quality when it is fit for its intended use in operations, decision-making and planning. Literature shows that, when it comes to IQ measurement, questionnaires are commonly used (see for instance Lee, et al., 2002; Winkler, 2004). Because disasters are very context and user sensitive, we focus on assuring IQ rather than DQ. More specifically, we aim to measure a set of IQ dimensions during disaster management exercises. Since the IQ dimensions listed in the table are well tested, we use them for preparing the observation protocol and surveys as part of our field studies (Chapter 4).

## 3.3   System Quality

### 3.3.1   Definitions and frameworks

Similar to a product manufacturing system, an information system is sequential in that the output from a certain stage in the information management cycle becomes data for the next stage. From this perspective, we can use the term information to refer to both data and information (Strong et al., 1997). Information system quality (SQ) is a concept used to evaluate multiple dimensions of information systems that are required to produce information (Delone & McLean, 1992). SQ is focused on the characteristics of the information system itself rather than on the characteristics of its product (Delone & McLean, 1992). The dimensions of SQ 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. Overall, SQ has received less formal and coherent treatment than IQ in the Information Systems literature. While scholars have studied SQ dimensions in isolation and in detail, there are relatively view studies which threat these requirements as a coherent set of SQ characteristics (one example is Nelson, Todd, & Wixom, 2005).

Traditionally, scholars have related SQ dimensions to technical engineering requirements such as infrastructure reliability, maintainability and availability (up time). As technical systems became more tightly coupled and industries needed to be more agile, scholars also included requirements such as flexibility and adaptability in their SQ analysis. Particularly in the case of information systems where user support and satisfaction have become important in the design of such systems, scholars have also included requirements such as 'each of use' and 'user friendliness' for assessing SQ. In the late 90ths when systems were considered to be carriers for services, SQ requirements were often closely related to ease of use (Nelson, et al., 2005). Constructs such as Media Quality (Eppler & Muenzenmayer, 2002), Software Quality (Zeist & Hendriks, 1996) and Service Quality (Kahn, Strong, & Wang, 2002) have been proposed to capture similar dimensions. These interrelationships make it even more important to ensure conceptual clarity in the specification and distinction of constructs. Table 3-3 outlines a number of SQ related frameworks in the literature.

| Table 3-3: Some SQ frameworks provided in the literature | | |
|---|---|---|
| **Authors** | **Model** | **Constructs** |
| (Zeist & Hendriks, 1996) | Extended ISO Model focusing on Software Quality Elements:<br>» 6 Quality characteristics<br>» 32 Sub characteristics | *Characteristics* — *Sub-characteristics* |
| | | Functionality — Suitability, Accuracy, Interoperability, Compliance, Security, Traceability |
| | | Reliability — Maturity, Recoverability, Availability, Degradability, Fault Tolerance |
| | | Efficiency — Time behavior, Resource Behavior |
| | | Usability — Understandability, Learnability, Operability, Luxury, Clarity, Helpfulness, Explicitness, Customizability, User-Friendliness |
| | | Maintainability — Analyzability, Changeability, Stability, Testability, Manageability, Reusability |
| | | Portability — Adaptability, Conformance, Replaceability, Installability |
| (Eppler & Muenzenmayer, 2002) | Conceptual framework for the website context Elements:<br>» 2 media quality categories<br>» 8 media quality dimensions | *Categories* — *Dimension* |
| | | Optimized Process — Convenient, Timely, Traceable, Interactive |
| | | Reliable Infrastructure — Accessible, Secure, Maintainable, Fast |
| (Leung, 2001) | Adapted and Extended ISO Model for Intranets Elements:<br>» Adaptation of Zeist & Hendriks Extended ISO Model, applied to Intranet environments<br>» 6 SQ characteristics<br>» 32 sub-characteristics | *Characteristics* — *Sub-characteristic* |
| | | Functionality — Suitability, Accuracy, Interoperability, Compliance, Security, Traceability |
| | | Reliability — Maturity, Fault tolerance, Recoverability, Availability, Degradability |
| | | Usability — Understandability, Learnability, Operability, Luxury, Clarity, Helpfulness, Explicitness, User-Friendliness, Customizability |
| | | Efficiency — Time Behavior, Resource Behavior |
| | | Maintainability — Analyzability, Changeability, Stability, Testability, Manageability, Reusability |
| | | Portability — Adaptability, Installability, Replaceability, Conformance |

Table 3-3 lists a range of variables for assessing SQ. Since information systems are socio-technical systems including human roles, procedures and technical artifacts (see Chapter 1), the variables also cover a range of characteristics on the interfaces between the social and technical components of information systems. We discuss some measures for SQ in the next section.

### 3.3.2  Measuring System Quality

SQ reflects the more engineering-oriented performance characteristics information systems. In contrast to assessing IQ, one will find less guidance for assessing SQ in the literature. Based on the measures proposed in Nelson et al (2005), we outline some instruments for assessing in table 3-4.

**Table 3-4: SQ dimensions and measurement items (adapted from Nelson et al, 2005)**

| Dimension | Measurement items |
| --- | --- |
| Accessibility | The degree to which a system and the system-related information it contains can be accessed with relatively low effort |
| Reliability | The degree to which a system is dependable (e.g., technically available) over time |
| Response time | The degree to which a system offers quick (or timely) responses to requests for information or action |
| Flexibility | The degree to which a system can adapt to a variety of user needs and to changing conditions |
| Integration | The degree to which a system facilitates the combination of information from various sources to support business decisions |

Table 3-4 outlines some tested measurement items for SQ dimensions. Compared to IQ dimensions which can only be indicated by end users (i.e., relief workers), the majority of SQ dimensions (except flexibility) can also be measured by information system architects, operators or observers. Since the SQ dimensions listed in the table are well tested, we use them for preparing the observation protocol and surveys as part of our field studies (Chapter 4). The next section discusses kernel theories from which we surface pathways towards the assurance of IQ and SQ in PSNs.

## 3.4  Conventional methods for assuring IQ and SQ

This study is not the first to consider methods for assuring IQ and SQ, albeit research on assuring IQ and SQ during multi-agency disaster response is almost absent. Factors that complicate the quality assurance process are abundant in the literature. Kwon and Zmud (1987) for instance have classified factors affecting IQ into individual, task-related, innovation-related, organizational, and environmental characteristics. Tornatzky and Fleischer (1990) have also suggested that the extent of IQ is affected by technological, organizational, and environmental context. Other, more recent studies (e.g., Patterson, Grimm, & Corsi, 2003) indicated that IQ is also affected by organizational size, structure, and performance, supply chain strategy, transaction climate, supply chain member pressure, and environmental uncertainty. Moreover, studies (e.g., Russell & Hoag, 2004) have concluded that specific

features of organizations themselves, including structures, climates, and cultures of organizations, will influence IQ. When we consider measures to assure IQ and SQ, Tsai and Ghoshal (1998) suggest that an organization will have better information when knowledge is shared more easily within the organization. Teece (1996) predicts that the cumulative nature of technologies influences the resulting IQ. Others (e.g., Grant, 1996) have also concluded that an organization with rich experience in the application or adoption of related technologies will be more able to assure IQ. Amabile (1988) suggested that enhancing management skills, organizational encouragement for information sharing, and support of information resources would help the improvement of IQ within the organization. Tornatzky and Fleischer (1990) claim that informal linkages among employees, human resource quality, top manager's leadership behavior, and the amount of internal slack resources would significantly influence the training IQ assurance capabilities. Considering all these factors, quality assurance in multi-agency settings is a wicked or ill-structured problem with many variable causes and alternative solutions (see chapter 2 for further explanation of wicked problems).

Scholars focusing on more stable business environments and single organizations propose some specific methods for assuring IQ and SQ. Often, these methods are grounded in analogies between information and typical manufacturing products and analogies between information systems and production processes. According to (Al-Hakim, 2007) the analogy between information and typical products enables organizations to apply the classic principles and foundations of product quality management to quality management of data and information products from an engineering point of view. As a result several conventional methods are proposed in the literature for assuring IQ and SQ. Methods provided in the literature include data cleansing & normalization (Hernandez & Stolfo, 1998) & Stolfo, 1998), data tracking and statistical process control (Redman, 1995), data stewardship (English, 1999), dimensional gap analysis (Kahn, Strong, & Wang, 2002). These approaches employ control techniques (e.g., edit checks, database integrity constraints) to assure data quality. Usually, these methods involve four steps: (1) profiling and identification of data quality problems, (2) reviewing and characterization of expectations in business rules, (3) instrument development and measurement and (4) solution proposition and implementation.

While conventional methods have proven to assure higher levels of data qaulity in less dynamic and single organizational environments, these methods are not suitable for addressing the IQ and SQ challenges during multi-agency disaster response. While most of the stated methods focus on well-defined data quality optimization within a single organization, multi-agency information management involves a different set of challenges, including unpredictable information needs, heterogeneous data sources and rapidly changing information objects. Another reason for arguing that these conventional approaches are not suited for achieving our research objective is that they tend to neglect the context of use. "Clearly, the notion of information quality depends on the actual use of information" (Huang, Lee, Wang, 1999, p.17). Similar to the previously mentioned methods for assuring IQ, conventional methods for SQ put little emphasis on the information management in a multi-agency context. Most of the SQ assurance methods in mentioned in the literature focus on IT infrastructure enhancement, for instance by adding hardware for increased performance, speed and reliability. There are also an increasing number of methods focusing on improving technical interoperability and mobility

(Miller, Granato, Feuerstein, & Ruffino, 2005). Literature also provides methods for on reducing information overload, including information filtering (Atoji, Koiso, Nakatani, & Nishida, 2004) and context dependent interface adaptation (Chen & Dahanayake, 2006). The cited studies acknowledge that quality assurance is a complex process, in which the difference between costs and required quality depends on the context of use and organizational requirements.

To conclude this section on the conventional methods for IQ and SQ assurance, we underline the need for considering the multi-actor environment and the dynamic information demand and supply that characterize multi-agency disaster response. Previous studies have also underlined this need (Petak, 1985; Turoff, Chumer, Van De Walle, & Yao, 2004). The discussed methods firmly rest upon technical optimization algorithms and solely focus on addressing isolated IQ or SQ variables such as correctness and overload. Consequently, the conventional methods suggest comprehensive, costly, and lengthy technical interventions instead of socio-technical principles that are easier to understand and implement before and during disaster response. Moreover, the intra-organizational focus of these methods do not allow organizations to optimize the effectiveness of their IQ and SQ initiatives in a network scope, and therefore lack the necessary commitments from all stakeholders. All of these commitments must be oriented to avoid some kinds of potholes that can generate serious problems such as invalidated information, barriers to information accessibility, or no information sharing across a network of agencies. Having discussed the strengths and limitations of the conventional approaches, we elaborate on two kernel theories for assuring IQ and SQ next. These theories are grounded in the socio-technical perspective, meaning that they include both technical and non-technical pathways for assuring IQ and SQ. Finally, the scope of these two theories extends beyond the organization, recognizing the interdependencies between organizations operating in a network.

## 3.5    Pathways from coordination theory

As discussed in the introduction, coordination theory is one of the theories that provide pathways for assuring IQ and SQ. This section proceeds by presenting some background on coordination theory. This section concludes with four pathways that can help us to design information systems that assure higher levels of IQ and SQ for relief workers.

### 3.5.1    Background on coordination theory

Coordination Theory suggests identifying the dependencies between the tasks the different group members are carrying out and the coordination mechanisms the group use to coordinate their work and then considering alternative mechanisms (Crowston, Rubleske, & Howison, 2006). Numerous scholars from various research domains (e.g., economics, public administration and information systems) have studied the construct of coordination (e.g., Grote, Weichbrodt, Gunter, Zala-Mezo, & Kunzle, 2009; Ren & Fussell, 2008). Generally, people intuitively know what 'coordination' means; yet have trouble in agreeing what it really is. In general, coordination in organizations refers to the alignment of individuals' actions (Heath & Staudenmayer, 2000). The need for coordination is a consequence of the division of labor; division of labor leads to specialization and concentration which is expected to result in higher productivity, efficiency, and, ultimately, competitive advantage (Adam Smith, 1776). The other side of the coin is that division of labor

causes interdependence among organizational tasks and members that need to be integrated or coordinated. In other words, coordination and interdependence are intertwined. This linkage is clearly expressed in the definition of coordination by Malone and Crowston (1994), who define coordination as "managing interdependencies" (p. 87), between actors, goals, and activities by means of various mechanisms". The need for resources is "the most important factor that stimulates inter-organizational coordination" (Van de Ven and Walker, 1984, p. 617). Coordination has traditionally been defined from an organizational-design perspective where rules, modalities, and structures are used to meet the information-processing demands of the environment (Faraj & Xiao, 2006). Previous research (e.g., March & Simon, 1958; Van de Ven, Delbecq, & Koenig, 1976) on coordination emphasize the management of resources (e.g., information, technology, personnel) through well-understood administrative coordination mechanisms (e.g., task assignment, resource allocation, input integration). Table 3-5 outlines some coordination mechanisms provided in Larsson (1990).

| Table 3-5: Several 'classic' coordination mechanisms (adapted from Larsson, 1990, p. 7) | |
|---|---|
| **Author(s)** | **Coordination mechanism(s)** |
| March & Simon (1958) | Standardization <br> Planning <br> Feedback |
| Thompson (1967) | Standardization <br> Planning <br> Mutual adjustment |
| Galbraith (1973) | Rules, programs & procedures <br> Hierarchies of authority <br> Goal setting <br> Slack resources <br> Self-contained structure <br> Vertical information systems <br> Lateral relations |
| Mintzberg (1979) | Mutual adjustment (individual work) <br> Direct supervision <br> Standardization of work <br> Standardization of outputs <br> Standardization of skills <br> Mutual adjustment |
| McCann & Galbraith (1981) | Hierarchies of authority <br> Rules, programs & feedback <br> Interactive planning <br> Spatial-physical strategies <br> Lateral control |

According to Table 3-5, scholars have proposed various modes for implementing and measuring coordination, including coordination by program or feedback (March & Simon, 1958), impersonal versus mutual adjustment (Van de Ven, et al., 1976) and formal versus informal mechanisms (Kraut & Streeter, 1995). Taking

an contingency perspective, Thompson (1967) defines three types of coordination: standardized, planned, and mutual adjustment. Under standardization, there are established rules or routines for how people should coordinate their activity. As with traffic rules, standardization improves performance per unit cost, by reducing coordination costs in both financial and cognitive terms, because rules remove many uncertainties about how people should coordinate their behaviors.

In some task environments, team members must plan their coordination processes in relation to the immediate tasks that that they need to perform. They will establish task-dependent schedules, work assignments and milestones. When the task environment is not easily standardized or planned, team members have to coordinate through continuous mutual adjustments to each other's activities. This requires constant communication to make sure that coordination requirements (and expectations) are clear and that team members perform activities with minimal confusion and maximum utility. If a team coordinates through mutual adjustment, for instance during disaster response, team members will need to identify with whom to connect, notify them when they sent information, transmit and identify the nature of the information, confirm that the information has been received and any subsequent synchronization of when to respond to it. In contrast, if they can standardize on a shared database, with a standardized schema, with synchronized postings, additional human actions for connection, notification, confirmation and synchronization can be virtually eliminated. Hence, IT (in this case a shared information management application) can facilitate moving from the more costly mutual adjustment behaviors to less expensive (and faster) standardization.

Thompson (1967) also identified three general types of task processes: long-linked, mediating, and intensive. Long-linked processes require the completion of various task activities over time, like an assembly line. A general assembly line process is a long-linked process because collection must precede analysis, which precedes production. Mediating processes link together individuals or groups that want to be interdependent for their mutual benefit, such as a broker mediating between those who to buy and sell stock. Intensive task processes are directed at changing an object, where the specific actions taken depend on feedback from the object. Disaster management operations are intensive processes, where the next operation against a target depends on the effects of earlier operations. At this point, one can see a relationship between the type of coordination and task processes (long-linked and standardization, intensive and mutual adjustment). This relationship is not deterministic, implying that scholars should also consider other organizational and environmental dimensions. Moreover, information technology can change this relationship as well.

Drawing on the information processing perspective, Galbraith (1973), postulates that in order for organizations to achieve coordination across and between its contingencies, organizations need to process information. Yet, information is costly, so organizations must balance their need to process information with their ability to do so. Whenever this match is not present, meaning, whenever the organization processes too much information or too little information, the organization is misaligned; there is a misfit between its contingencies.

Taking a more process-centric perspective, Malone and Crowston propose a "coordination theory" that emphasizes the management of interdependencies among resources and activities and define coordination as 'managing dependencies between activities' (1994b, p. 90). These authors characterize various interdepend-

encies on the process level and a variety of coordination mechanisms that are useful as building blocks to solve information management problems in organizations or to design novel organizational processes. According to this process centric view of coordination, a process consists of three types of elements: resources, activities, and dependencies. A resource is produced and/or consumed during a process. For example, a software application used during disaster information management is a resource. Equivalently, specification documents, maps, sensors and experts are resources in an information management process. An activity is a partitioned action that produces and/or consumes resources; for example, 'collecting information' is an activity. Activities are themselves processes and we use the two terms interchangeably. A dependency is a relation among activities mediated by producing or consuming resources; for example, there is a dependency between 'collecting information' and 'disseminating information'. This state is characterized more or less by symmetry among the parties to the relationship. Connections between the organizations involved are non-random. However, there is no implication of subordinate status for any of them (Chisholm, 1992, p. 42).

Thompson (1967) mentions three general types of interdependence among unit personnel and organizational units: pooled, sequential, and reciprocal. In pooled interdependence, each team provides a discrete contribution to the whole by collating (or pooling) its obtained information and knowledge. In sequential interdependence, however, the product of one team depends on the output of another. The responding agency takes no action unless they receive a request and the requesting agency cannot proceed until its request is fulfilled. Finally, in reciprocal interdependence, teams pose critical contingencies for each other that have to be resolved before taking action. Disaster management operations often have a reciprocal interdependence. Whether or not different operations can be undertaken depends on the availability of certain resources and, in turn, the availability of those resources depends on previous and planned operations.

From a process centric perspective, Malone and colleagues (1994) distinguish three basic types of dependencies: flow, sharing, and fit. A flow dependency occurs when one activity produces a resource that another activity uses. A sharing dependency occurs when multiple activities all use (or could use) the same resource. A fit dependency occurs when multiple activities jointly produce a single resource. Using these three basic types, any process can be decomposed into a structure of activities and dependencies. The strength of this view on coordination is its recognition of the complexity of interdependencies in organizational work. Scott (1992) notes that greater interdependence is associated with more elaborate coordination structures. He suggests that higher levels of interdependence necessitate more extensive and complicated coordination mechanisms. On the other hand, a weakness of this view is the assumption that the environment is predictable enough to characterize existing interdependencies and that architects can predefine mechanisms for dealing with various contingencies. In disaster management environments, we need to acknowledge that not all relevant information is known, and that previously known conditions may be in a state of flux (Kapucu, 2006).

The central problem arising from a state of interdependence is to reduce uncertainty (particularly that which threatens the organization) to an acceptable level by ordering the behaviors of all relevant organizations to lessen the extent to which they impinge on each other's behavior and increase the benefits from their behaviors (Chisholm, 1992). Organizations attempt to reduce uncertainty in vari-

ous ways through expansion and merger, consolidation and centralization, government regulation and coordination. Here, 'uncertainty' refers to the lack of information about future events so that alternatives and their outcomes are unpredictable, where 'events' are understood as actions by other organizations in the focal organization's environment

### 3.5.2 Concerns regarding hierarchical coordination in public safety networks

Relief agencies have been noted to take on a more military type hierarchical structure when multi-agency disaster response is necessary (Bigley & Roberts, 2001). "A hierarchy of information and communication coincides with a functional hierarchy. Lower-level operatives are briefed on a very limited 'need to know' basis and are often oblivious to the wider context and significance of their actions" ('t Hart et al. 1993: p. 18). This reflects the belief that PSNs carry out the most effective repression operations under rigid control, exercised convergent with intra-agency authority structures. In such hierarchy-based PNSs, subordinates only share information with their commanders. The major strategic decisions are made at the highest echelons and are filtered down and more detail is added as they pass through to the lower echelons (top-down/bottom-up principle). Throughout this flow of information, an asymmetry of information load is maintained, often resulting in fragmented situation awareness (cf. Militello, Patterson, Bowman, & Wears, 2007). In a hierarchy, the flow of information is coordinated through adjacent steps, by controlling and directing information to the higher and subordinate echelons (Malone, Yates, & Benjamin, 1987). The advantage of this coordination approach is that the number of interactions and interdependencies between relief workers is often know and limited since the linkages are based on long lasting relationships and procedures. In many public service domains, hierarchical coordination was embraced from the start and has been intensified because of the demand for stability, transparency and accountability in the public sector. Yet, the characteristics of hierarchical coordination do not leverage high IQ and SQ during disaster response.

The traditional critique here is that "as organizations face requirements of urgent decision-making and immediate response, they cannot rely on formal, time-consuming policy procedures" (t' Hart, 1993, p. 14). Central coordinating schemes do work effectively under conditions where the task environment is known and unchanging, where it can be treated as a closed system (Chisholm, 1992, p. 10). However, disaster situations are notorious for the increased uncertainty, a greater density of communication and the rapid rate of decision-making (Kapucu, 2006). Accordingly, several authors have demonstrated the limitations of hierarchical coordination in PSNs (e.g., Argote, 1982; Auf der Heide, 1989; Comfort, Dunn, Johnson, Skertich, & Zagorecki, 2004). Herbst describes four assumptions of hierarchical organizations that do not match with complex, dynamic environments: (1) a task can nearly always be decomposed into smaller and smaller independent parts, (2) an organization has a simple inflexible structure which can be visualized in an organogram with lines of responsibility, (3) organizations are of a uniform type, and (4) organizational units have a single, exclusive boundary (1976, pp. 28-33). When it comes to disaster response, the model of hierarchically coordinating resources and information is often criticized for not being flexible and not supporting emergent events and processes (Drabek & McEntire, 2003). The basic assumption underlying hierarchical structures is that if the problem is well defined, if the

rules of operation are clearly specified, and if systems can be closed to outside interference and disturbance, they can function without error. Another assumption is that the hierarchy of agencies is in command of all activities and resources and can control all other disturbances. The strength of such systems is that they function well in stable environments. Their weakness is that they do not function well in dynamic and changing conditions of a disaster environment. Worse, personnel in hierarchical structures, trained to follow the rules, might have difficulty devising strategies of action that will work when the rules no longer apply. Such organizations often are unable to respond effectively to urgent, time-critical demands (Comfort, 1999).

Traditional coordination theory emphasizes the how (i.e., the mode) of coordination as opposed to the what (content) and when (circumstances) of coordination (Thompson, 1967). This distinction becomes increasingly important in complex and dynamic environments where there is less reliance on formal structure, interdependencies are changing and work is primarily performed in heterogeneous teams. Faraj and Xiao (2006) challenge much of the traditional approach to coordination and suggest that in settings where work is contextualized and non-routine (e.g., during disaster response), traditional models of coordination are insufficient to explain coordination as it occurs in practice. These scholars mention two conditions under which the traditional coordination theory fails: (1) when expertise is distributed and work is highly contextualized and (2) when it is crucial to avoid error under time pressure. Both of these conditions apply to disaster response (Comfort, Ko, et al., 2004).

### 3.5.3 Focusing on the coordination of information management activities

Through literature review, we found that coordination theory is a well-studied and applied theory in the information systems domain. While several constructions and operationalization's of coordination theory exist in the literature, the most common construction in the IS field is the management of interdependencies between actors, goals, and activities by means of various mechanisms (Malone & Crowston, 1994a). While this definition is clear on what is to be coordinated (interdependencies), it did not help us to find principles for assuring IQ and SQ. A more detailed examination of this and other definitions for coordination led us to conclude that several resources (i.e., humans, equipment and information) and processes (i.e., resource allocation, rescue operations and information management) can be coordinated via different roles (i.e., team leader, information manager and IT operator) and objects (i.e., uniforms, standards and IT).

Based on this perspective on coordination, our research focuses on the coordination of information (as a resource) and information management (as a process) through roles and objects. Often regarding the combination of roles and objects as mechanisms for designing coordination structures, scholars have long debated on the level of centralization or decentralization of these mechanisms as important steering instruments for coordination. Centralization has often been associated with benefits such as accountability, control and economic efficiency, whereas decentralization has often been associated with benefits such as flexibility, redundancy and speed. King (1983) has brought some clarity in this debate by identifying three dimensions to the centralization issue: (1) concentration of decision-making power, (2) physical location, (3) function or the position of an activity or

responsibility. We use these dimensions to navigate the large body of knowledge on coordination. In the spectrum of archetypical organizational designs (Mintzberg, 1980), hierarchies are fully centralized for all dimensions, whereas networks are fully decentralized for all dimensions. However, as stated in chapter 1, PSNs are a special type of design that includes a hybrid form of these dimensions. On the first dimension, there is little design space. As discussed in Chapter 4, decision-making power in PSNs is grounded in the multi-agency teams that are activated on the strategic, tactical and operational echelons. Reallocating decision-making power is beyond the scope of this dissertation. The second dimension contains more design space since PSNs include several, physically distributed teams with varying information management capabilities. The third dimension also contains some design space, especially when looking for ways to decentralize and distribute information management activities and capabilities in concert. The second and third dimension led us to four pathways for assuring IQ and SQ from coordination theory. We discuss these pathways next.

### 3.5.4 The pathway of Orchestration

The first pathway provided in Coordination Theory is IT enabled orchestration. Scholars such as Powell (1990) and later Clemons et al. (1993), have studied ways to coordinate organizations other than hierarchal and emphasized the need for inter-organizational information sharing. Moreover, they have discussed the possibilities for hybrid forms of coordinating activities that are suited for dealing with different conditions. In Drucker (1988) we found some interesting, proposed prototypes for organizations of the future stating that "companies will resemble universities, hospitals and symphony orchestras" (p. 5). In these three prototypical agencies, knowledge and responsibility are disseminated across the whole agency, and yet the agency wide goals are achieved through orchestration. In this view, information management responsibilities can be centralized (as occurs, for example, in a symphony orchestra, where we have the figure of the conductor as a general coordinator), but control is distributed and we find high levels of autonomy at all levels of the agency.

Whereas there is no single and universally accepted definition or framework for orchestration, scholars seem to agree on the goal of orchestration. Drawing on the example of a music orchestra with a variety of musical instruments, the goal of orchestration is to facilitate a variety of roles and objects to function in concert (i.e., a coherent way that serves the purpose of all stakeholders). As such, this pathway enables us to find ways of maximizing the benefits of decentralization, while retaining the benefits of centralization.

The first mentioning of the term Orchestration can be traced back to the work of Otto Neurath. While Neurath already hinted towards the concept of orchestation in papers such as "On the classification of systems of hypotheses" (1916), his latter paper "The Orchestration of the Sciences by the Encyclopedism of Logical Empiricism" (1946) was the first to explain this concept in more detail. Neurath spoke of a 'mosaic', an 'aggregation', an interdisciplinary 'orchestration' of the sciences as 'systematization from below' rather than a 'system from above', especially (Neurath, 1983). In this vision, knowledge transfer was the main process that required orchestration. One of the assumptions of Neurath was that humans only possess partial information (Mertens, 2007, p. 34). According to encyclopedism, science is a hybrid of 'high' knowledge, i.e., global and theoretical knowledge in the

traditional sense, and 'low' knowledge, i.e., local and practice-oriented knowledge. In contrast to virtually all traditional philosophical currents, Neurath's encyclopedism was not afraid of the ambiguities and lack of homogeneity in knowledge. Neurath proposed that one should do justice to all the often diverging currents of knowledge by means of appropriate orchestration, leading to what he called "the democratisation of knowledge" (Neurath, 1983). Later, other scholars have studied and extended the concept of orchestration for other domains such as value chains (Hinterhuber, 2002), business services (Sadiq & Racca, 2004), e-government (Janssen, Gortmaker, & Wagenaar, 2006) and business networks (Busquets, 2010). Accordingly, scholars have proposes multiple types of orchestrators including process orchestrators, workflow orchestrators and web service composition orchestrators. The difference between an orchestrator and an architect is that the latter designs something static, such as a house, a bridge or a landscape, that is, something that does not vary in time. The architect designs only the deliverable, not the process used to deliver it. An orchestrator designs a delivery of music rendered in time, in the harmony and tempo needed to achieve a desired effect.

When it comes to the structure of orchestration based information systems, scholars often use hybrid, mix mode (Holland & Lockett, 1997) or 'heterarchical' architectures. The term heterarchical indicates that there is no hierarchy of information managers. Heterarchical control structures have distributed locally autonomous entities that communicate with other entities without the master/slave relationship found in a hierarchical architecture. According to Dilts et al., (1991) the field of distributed computing is a source for a number of justifications for the principles of heterarchical control architectures. Implying the decentralized function of information management in a decentralized and physically distributed network structure, orchestration is not about the first dimension of King (1983), it's primarily about the position of the information management capabilities in a PSN. As such, orchestration does not require hierarchical organizations (i.e., police, fire department, and medical services) to fully centralize authority and decision-making when forming a public safety network, and yet decentralize information management activities such that the IQ and SQ can be assured beyond organizational boundaries. This special form of coordination appealed to our interest since it does not dictate the destruction of variety in the current IS landscape of PSNs. Drawing on Ashby's law of 'requisite variety' (Ashby, 1958), we argue that some variety in roles and objects is necessary, especially when dealing with complex and unpredictable situations such as disasters. Hence, we argue that stakeholders (e.g., information system architects) should only pursue uniformity when the definite and universal solution is available for all sorts of disasters. This does not mean that orchestration does not require any standardization. While demanding some level of standardization in message exchange (for instance using web-services), orchestration allows for co-existing of several (proprietary, legacy, or preferred) information system components and technologies.

A final component we should elaborate on when it comes to orchestration is its enablement through IT. Fulfilling the role of orchestrator within and between agencies requires highly modular and flexible IT. Scholars have advocated the development of Service Oriented Architectures (SOA) for this purpose. SOA provides integration and virtualized IT services (Bieberstein, Bose, Walker, & Lynch, 2005). SOA is the trend for a distributed computing grid where applications are refactoring into highly accessible, loosely coupled, discrete business services (Pereira,

2009). Accordingly, each service is built only once, and when upgraded all user applications and systems receive the upgrade. Following Khalaf et al., (2006), the purpose of SOA is to provide application functions as a service offered on the Internet, in an environment that is characterized by being distributed, heterogeneous, and very dynamic and where boundaries of both system and organizations are passed over. Thus, we can consider SOA as a style of designing an information system architecture that enables the creation of applications built by effectively combining loosely coupled and interoperable services. From a SOA perspective, orchestration is about the integration of two or more services (Emmerich, Butchart, Chen, Wassermann, & Price, 2006). The most common technology used for establishing SOA is web services. Web services provide a simple programmatic interface implemented on standard Web protocols and are addressable by a URL. The study by Shen et al., (2007) indicates that the Web Services pattern is becoming the dominant form of distributed computing.

### 3.5.5   The pathway of Boundary Spanning

The second pathway provided in Coordination Theory is boundary spanning. Early on, the innovation literature identified the significance of environmental information gathering and assimilation to organizational renewal (Lindgren, Andersson, & Henfridsson, 2008). Such information gathering and assimilation is associated with specific boundary-spanning roles at different stages in the innovation process (Tushman, 1977). On a general level, boundary spanning can be seen as the activity of making sense of peripheral information that is perceived relevant to expand the knowledge at the center of a given organizational context (Lindgren, et al., 2008). So-called boundary spanners perform this activity, i.e. individuals who operate at the periphery or boundary of an organization, relating the organization with elements outside it (Tushman, 1977). Essentially, these individuals scan the environment for new information, attempting to determine its relevance vis-à-vis information already assimilated in the organization. In this boundary-spanning process, the individual, the organization and the environment are parts of a network of interactions and organizational knowledge creation (Cohen & Levinthal, 1990). Therefore, roles that link their organizations with others are referred to as boundary spanners (Aldrich & Herker, 1977; Thompson, 1967). Drawing on this understanding, scholars such as Levina & Vaas (2005) consider boundary spanning as an competence in practice.

As a disaster evolves, relief agencies operate more distributed and dynamic and the PSN will be increasingly populated by multiple functional, geographical, hierarchical and professional boundaries. The inherent complexity of such settings makes it essential for relief agencies to leverage their boundary-spanning practices. It is therefore necessary to develop capabilities for combining multiple sources of expertise (Kogut & Zander, 1992) and establishing boundary-spanning practices (Levina and Vaas, 2005). In this context, capabilities are dynamic, referring to "learned and stable patterns of collective activities through which the organization systematically generates and modifies its operating routines in pursuit of improved effectiveness" (Zollo & Winter, 2002, p. 339).

Using various theoretical lenses, researchers have explored the nature of boundaries as the demarcation between an organization and its environment (Scott, 1992). After examining existing work, we found that boundary spanners should possess knowledge of the relevance between various pieces of information

and the organizations they link together and make decisions concerning the distribution of gathered information. Boundary spanners influence the linkages between the various agencies in a network and at the same time represent the perceptions, expectations, and values of their own agencies to those groups (Friedman & Podolny, 1992). For humans to perform the tasks of boundary spanning, scholars have underlined the importance of information technologies (ITs) acting as 'boundary objects' (Levina & Vaast, 2005; Lindgren, et al., 2008). In particular, IT artifacts have been recognized as having the potential to be adapted to local needs, while at the same time providing a source of common identity across boundaries.

Star & Griesemer (1989) specify boundary objects as "objects that are plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (p. 389). Boundary objects may include physical product prototypes, design drawings, shared IT applications, engineering sketches, standardized reporting forms or even shared abstract constructs such as product yield. Boundary objects act as 'brokers' between interactions with other organizations, but at the same time they act as gatekeepers, selecting and filtering information. For boundary spanning to emerge, a new joint field of practice must be produced (Levina and Vaas, 2005), which can be a shared IT-application. In the work practice literature, the notion of boundary object has been used to capture this potential and to advance the idea of IT as an important resource for boundary spanners in establishing practices that bridge communities-of-practice (Lindgren, et al., 2008). Therefore, boundary spanning, i.e., the roles of boundary spanners and boundary objects, become extremely important in PSNs where a large number of heterogeneous agencies have to develop a common operational picture and jointly respond to the effects of a disaster. This boundary spanning approach (for instance via orchestrators) can also solve the problem of trying to establish a relationship between relief agencies and a private companies by adjudicating passwords to all relief workers.

### 3.5.6    The pathways of Advanced Structuring and Dynamic Adjustment

The third and fourth pathways provided in Coordination Theory come from the contribution of Gosain, Malhortra and El Sawy (2005). The work of these scholars is grounded in the seminal work of March and Simon (1958) who suggest that coordination can be based on pre-established schedules (coordination by plan) and coordination that involves transmission of new information (coordination by feedback). This coordination framework has been investigated in interpersonal coordination in organizational settings (Van de Ven, et al., 1976). Drawing on March and Simon's work, Gosain et al. (2005) provide two pathways for our research: (1) advance structuring of inter-organizational processes and information exchange that allows collaborating organizations to be loosely coupled, and (2) IT-supported dynamic adjustment that allows organizations to quickly sense change and adapt their network linkages. The former refers to things you do up-front to reduce the information processing needed to cope with change. The latter refers to increased information processing capabilities that allow for "on-the-fly" adaptation.

The rationale behind these pathways is that organizations (i.e., relief agencies) operating in dynamic environments, need to seek to consciously lay out prescribed activities by planning in advance, while at the same time they need to supplement these with spontaneous ongoing adjustment to cope with unforeseen scenarios (Beekun & Glick, 2001). While the literature (e.g., Tan & Sia, 2006) is

somewhat inconclusive on the results of these pathways, we concluded that these pathways emphasize the development of specific information management capabilities. In this light, advance structuring suggests the development of preemptive and protective capabilities prior to a disaster. Loose coupling is an example of a preemptive capability, whereas dependency diversification is an example of a protective capability.

The idea here is that the upfront development of information management capabilities will require fewer efforts to assure IQ and SQ during disaster response. Following this pathway, relief agencies can equip themselves with the dexterity required for preemptive capabilities before the events that take place during a disaster, consciously creating a range of information management capabilities before they are needed. Relief agencies can also use redundancy mechanisms, such as information or resource buffers, as a protective measure to guard against a potentially damaging situation and to allow a strategy to remain viable in spite of changes in the environment. Complementary to this pathway, the pathway of dynamic adjustment suggests the creation of exploitative and corrective capabilities. Environmental scanning is an example of an exploitative capability and reactive adaptation is an example of a corrective capability. Ex-post information management capabilities exploit or capitalize on information beyond the organizational boundaries through constant scanning of (external) data sources and social networks, and the ability to recover from infliction and ameliorate the impacts of technology failures and mistakes are also critical to information coordination efforts in PSNs.

Gosain et al. (2005) provide three examples of design principles that have been found from the advanced structuring pathway: (1) standardize process and content interfaces, (2) modularize interconnected processes by breaking up complex processes into sub-processes that are performed by different organizations independently and, (3) structure data connectivity in order to exchange structured transaction data and content with another enterprise in electronic form. Following the dynamic adjustment pathway, the coordinating entities learn to adjust quickly to diverse information structures across partners or over time. It is also expected to improve the ability of an enterprise in a supply chain relationship to continuously 'morph' in changing environments (Rindova & Kotha, 2001). Dynamic adjustment requires making changes 'on-the-fly' as necessitated by the business environment. As an example, in the face of a disruption, the supply chain processes need to be dynamically reconfigured so that different supply chain players remain in sync (Gosain, et al., 2005). Cherns (1987) calls this 'variance control' that can achieved by equipping an information architecture recursively (i.e., the agency components, the components' components, etc.) with the capability to monitor the environment and the autonomy to update their work routines accordingly.

## 3.6   Pathways from Network Centric Operations

The previous section presented four pathways from coordination theory that can help us to design information systems that assure higher levels of IQ and SQ for relief workers. We return to these pathways in chapter 6. This section elaborates on network centric operations (NCO) theory, a relatively new theory (compared to coordination theory). This chapter concludes with three pathways derived from NCO theory.

### 3.6.1    Background on Network Centric Operations

Before the 'discovery' of organizational networks and the mechanisms of different types of coordination, social coordination was considered to take place in two distinct forms: hierarchies and markets (Meuleman, 2008, p. 33). Market coordination was the second ideal type that was described after Weber's bureaucratic ideal type (Weber, 1952) had become the prototype for a classical hierarchy. Networks were, for a long time, considered a hybrid form of these ideal-types. Early work by Thorelli (1986) already argued that the network form is a distinct form of societal coordination, and not 'just' a hybrid form that combines hierarchy and markets. The network concept has become so popular, that in some domains, a new dichotomy emerges, namely hierarchy versus networks, while scholars neglect market governance (Meuleman, 2008). This is particularly true for the domain of Public Safety, in which network based coordination has caught the attention of various stakeholders.

Here, we refer to the concept of Network-Centric Operations" (NCO) (also known as "Network-Centric Warfare") that has been developed by David Alberts, Art Cebrowski, and John Gartska who are researchers of the U.S. Department of Defense. These scholars coined the concept of NCO in a series of the Command and Control Research Program (CCRP) articles starting in 1996. Defense scholars from other countries have also suggested similar concepts such as Network Enabled Capability (NEC) in the United Kingdom and Network Based Defense in Sweden. While several definitions that have been proposed for NCO (e.g., Stanovich, 2006; Van de Ven, Van Rijk, Essens, & Frinking, 2008), one definition that stands out is *"military operations that exploit state-of-the-art information and networking technology to integrate widely dispersed human decision makers, situational and targeting sensors, and forces and weapons into a highly adaptive, comprehensive system to achieve unprecedented mission effectiveness",* (Anon, 2000, p. 3). This definition stands out because of the emphasis on employing IT for NCO. Netcentricity emphasizes horizontal information sharing among peers rather than vertical information sharing among commanders and subordinates. In theory, the small-unit soldier who can access information and intelligence from all collection sources will be able to employ combat assets such as air support, artillery, and electronic warfare with much more precision, timeliness, and effectiveness than what was possible with past capabilities (Stanovich, 2006).

In this study, a network refers to a group of agencies who exchange information and undertake joint activities, while organizing themselves in such a way that their individual autonomy remains intact. Important aspects of this definition are that the activities must be voluntary, mutual or reciprocal, and that belonging to the network does not affect autonomy or independence of the members (Tapscott et al., 2000). From a policy perspective, networks are portrayed as sets of interdependent organizations which have to exchange resources to realize their goals (Marsh & Rhodes, 1992, p. 11). Following this perspective, scholars characterize interdependencies within networks by their power-dependent nature. In a network, power is not concentrated, but distributed horizontally as well as vertically. The policy network approach requires recognition of the complexity of the interactions between different organizations involved in the policy-making arena. The network approach is based on a few important assumptions: 1) actors and their actions are viewed as interdependent, 2) relational ties between actors are channels for transfer of resources (material and/or nonmaterial), 3) network models focusing on in-

dividuals view the network structural environment as providing opportunities for or constraints on individual action, and, 4) network models conceptualize structure as lasting patterns of relations among actors (Wasserman & Faust, 1994). Conforming to these assumptions, the present study uses the network concept as a way to describe the multi-agency interdependencies among relief agencies. Accordingly, we use the term network as a metaphor to describe partnerships in which more than one agency is dependent on another to perform tasks effectively.

### 3.6.2   Assumed advantages of Network Centric Operations

Generally, scholars and practitioners advocate network based coordination approaches for several reasons (e.g., Powell, 1990; Thompson, Rances, Levacic, & Mitchel, 1996; Thorelli, 1986). Meuleman (2008) for instance, suggests that networks work well in knowledge-rich environments because they have superior information-processing capabilities; they are also more adaptable and flexible than hierarchies because of their loose coupling and openness to information (p. 163). Network forms of organization, unlike hierarchies or marketplaces, are agile and are constantly adapting as new links are added and dysfunctional ones are dropped (Contractor, Wasserman, & Faust, 2006). By fully utilizing the range of human and technical capabilities across a network of agencies, this coordination approach enables higher levels of adaptability. Perrow (1984) strongly advocates the adaptability of a loosely coupled system as a great advantage, especially in situations in which the system should be able to adjust to environmental changes. NCO harnesses the autonomy of individuals and seeks to empower the individuals (i.e., relief workers) in their ability to adapt to changing circumstances. The underlying tenets or hypotheses already hint towards assumed (untested) advantages over hierarchy based coordination models (Alberts, et al., 2002):

- A robustly networked force improves information sharing.

- Information sharing and collaboration enhance the quality of information and shared situational awareness.

- Shared situational awareness enables self-synchronization, and enhances sustainability and speed of command.

- These, in turn, dramatically increase mission effectiveness.

Drawing on these hypotheses, scholars have mentioned several expected benefits when adopting NCO. Table 3-6 presents a list of expected benefits when following the NCO approach to information sharing instead of the traditional hierarchical approach. The main premise behind this research is that the network-centric approach as used in the military domain could be useful in disaster situations, because both are multi-actor, complex situations with short decision-making time. Accordingly, in the public safety domain, the 'force' mentioned in table 3-6 would refer to an crisis management organization consisting of multiple governmental agencies, including municipalities, police departments, fire departments, ambulance services. However, we do not know how to leverage the outlined benefits of NCO and whether or not NCO can lead to higher IQ and SQ compared to hierarchy based information management.

**Table 3-6 Benefits expected from NCO capability development**

| Expected benefits | Explanation |
|---|---|
| Empowerment and user autonomy (Alberts & Hayes, 2007) | A network-centric organization has a decentralized organizational structure. Because of this decision making and responsibilities are shifted to lower levels in the organization empowering individual soldiers in their work. |
| Robust information sharing (Peer 2 Peer) (Gonzales et al., 2005) | In a network-centric environment, the various units (teams) operate fairly independent of each other. This means that failure in one unit does not (necessarily) have effect on other units. |
| High situational awareness (Alberts & Hayes, 2007) | Parts of the organization cooperate to produce actionable information, fusing many separate facts into a common picture of the battle space. |
| Flexible information systems (NESI, 2008) | Provide flexible information systems that can swiftly adapt to the information demands of a particular operational scenario. This is necessary because information needs are difficult to predict. |
| Rapid feedback on information sent (Gonzales, et al., 2005) | The independence and distributions of organizational units enables feedback on information sent between units. |
| Real time information flow support (Alberts & Hayes, 2007) | Information flow within NCO is synchronous, meaning that senders and receivers of information can only exchange information when both have contact which each other. |
| Enhanced quality of information (Alberts & Hayes, 2007) | Information superiority, which includes creating and maintaining a continuous, high quality information flow throughout the force helps to ensure a clear and common understanding of the situation. |

Until now, academic contributions regarding NCO are scarce. Therefore, the theoretical pathways in this theory remained on a conceptual level. In addition, scholars have not yet evaluated NCO on the assumed benefits outlined in table 3-6. Moreover, metrics for evaluating the level of netcentricity (i.e., zero netcentricity versus full netcentricity) are lacking. Yet, relief agency managers are showing increasing interest in the concepts behind NCO, particularly as responders prepare for an increasingly complex threat spectrum in a post-9/11 world (Stanovich, 2006). While we acknowledge that the relief agencies in PSNs deal with complex, hazardous and highly unpredictable events comparable to military missions, we need to underline that the heterogeneity in public safety networks may be a hurdle when seeking to leverage the advantages of NCO. Depending on the type and scale of a disaster, public safety networks consist of a variable set of agencies, each employing their own information coordination procedures and technologies (Bharosa, Lee, et al., 2010). Considering the characteristics of public safety networks, we express some concerns when adopting NCO as main approach for configuring information management architectures in the next section.

### 3.6.3 The pathway of Self-synchronization

The first pathway we provided in the NCO literature is self-synchronization. The pathway of self-synchronization was introduced by Cebrowski and Gartska (1998) in their seminal article "Network-Centric Warfare: Its Origin and Future". Alberts, Gartska, and Stein (1999) use this term to describe the operation of entities in the absence of traditional hierarchical mechanisms for command and control. According to the tenets of NCO, self-synchronization is the link between shared situational awareness and mission effectiveness. In their book "Understanding Command and Control" Albert and Hayes (2006) highlight that: "The magic of NCW is the emergence of self-synchronizing behavior" (Albert & Hayes, 2006, p. 2). In a later publication, Alberts and Hayes (2007) suggest that "self-synchronization leads to dramatic increases in both force agility and effectiveness" (p. 2). Often, self-synchronization is associated with visions of modern warfare in which individual soldiers are equipped with advanced digital headpieces. Drawing on its initial description in the literature, we developed a more PSN related understanding of what self-synchronization means and what it could leverage for relief workers. Firstly, we do not associate any specific technical features with this pathway. Instead, we focused on unlocking the potential of allowing every relief worker in the PSN to have access to the same information in the same format. Secondly, we considered self-synchronization as a way of empowering the relief workers to directly collect, use, update and distribute information anytime and anywhere in the PSN. Our understanding of this pathway draws upon the idea that subordinates have superior local knowledge, and if they understand the goals (commander's intent), rules of engagement, and plans (orders) of an operation, they can produce results superior to the centrally controlled organization. Figure 3-1 sketches the maturity path organizations need to follow before self-synchronization can be leveraged.



**Figure 3-1: The netcentric maturity model (based on Alberts, Garstka, & Stein, 2002)**
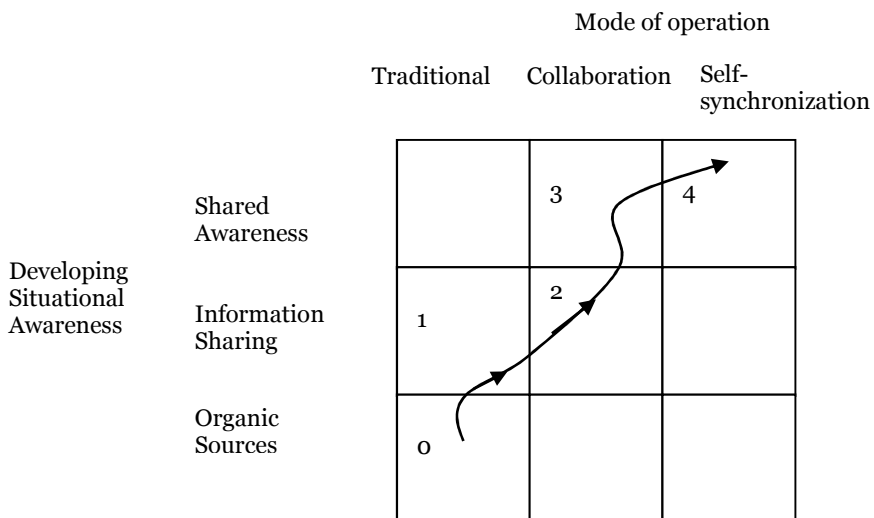
Figure 3-2 illustrates five consecutive stages of maturity in NCO. Level 0 represents a traditional or hierarchical approach to command and control which, for the most part, is based upon information from organic sensors and systems. Organic here refers to the assets of the agencies and teams in a network. Thus, in Level 0, information is not shared outside of pre-existing stovepipes and point-to-point flows. Moving to Level 1 involves a "post before use" strategy and a shift from push to pull that makes information far more widely available. Moving to Level 2 involves moving from a passive sharing of information to a collaborative process focused on understanding the information (putting it into context) and the situation to develop a higher quality of awareness. Moving to Level 3 involves discussions (collaborations) that go beyond what the information is and draw on the shared awareness through extensive interaction and collaboration. Finally, a move to Level 4 entails the adoption of a command approach rooted in the concept of self-synchronization. This figure suggest that the highest level of maturity is established when individuals (i.e., soldiers or relief workers) are empowered to synchronize themselves with the information available throughout the network.

### 3.6.4   The pathway of Reachback

The second pathway provided in the NCO literature is reachback. While self-synchronization refers to abilities of an individual or team of persons, reachback is associated with technology and is defined as "the electronic ability to exploit organic and non-organic resources, capabilities and expertise, which by design are not located in the theater" (Neal, 2000, p. 4). In general, reachback refers to a situation where resources, capabilities and expertise are at a physical distance from the area of interest, supporting the people in the area to perform their tasks. This pathway draws on the idea that higher headquarters enjoy larger staffs and larger reservoirs of knowledge, experience, and information management capabilities. This pathway suggest that the individual soldier, or in our case the relief workers, should have access to all information sources in the network, including experts and external (nonmilitary) data bases without the mediation of other individuals (i.e., commanders and control rooms). Therefore, we can consider reachback as a prerequisite for self-synchronization.

Given the advancement in information technology (higher connectivity at lower cost), reachback is becoming easier to implement. However, from a socio-technical perspective, we consider reachback as a pathway that goes beyond the implementation of technology alone. Following Custer (2003), reachback also raises questions regarding information access levels, sharing policies, and dissemination of sometimes security sensitive information in a network of agencies. This means that we need to be careful in selecting roles that that have full reachback. Moreover, since disasters are low frequency events, the level of reachback needs to be regulated to minimize the chances of improper use. This strengthened our view that reachback is not only an ability, but can also be a strategic choice to accomplish the goals of a PSN. As such, we have extended the understanding of reachback from a technical capability (no reachback versus full reachback) to a strategic capability (different levels of reachback for different roles at different moments) that stakeholders need to implement cautiously for security reasons.

### 3.6.5 The pathway of Information Pooling

The third pathway provided in the NCO literature is information pooling. Information pooling is not a new idea and has been coined by scholars in the area of Social Phycology and group decision support in the early eighties (Stasser & Titus, 1985). In later publications on NCO, this pathway for sharing information from various human and data sources in teams has regained attention. We consider task-related information known by all members of a multi-agency disaster response as 'shared information', while the information held only by one or few team members is 'unshared information'. Both types of information play important roles in team decision-making: e.g., shared or redundant knowledge may help establish a common situational picture and allow for swift decision-making.

On the level of information, NCO aims to empower relief workers to collect information anywhere at any time. In the Netherlands, this notion inspired the commanders of relief agencies to sketch a data pool as illustrated in Figure 3-2.

Figure 3-2[1] visualizes the aspired open and collective (netcentric) information sharing as a data pool. The data pool needs to be a 'national single window' or information market providing information that is accessible by all authorized relief agencies. The information in the data pool is the result of interconnecting various data sources in a PSN. The idea of using a data pool requires stakeholders to predefine arrangements on who delivers and maintains the data. After publication of the ASE rapport, there were no follow up publications demonstrating how to redesign existing information systems in accordance with the NCO vision sketched in Figure 3-2.



**Figure 3-2: NCO as a data pool (ASE, 2008)**

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[1] Illustration by Huib Jans, reprinted with permission.

The collection of task-relevant information known by every member is termed the pool and thus information pooling is the process of creating and enlarging the pool of shared information through group discussion. Information sampling is the process by which team members introduce task related information into a discussion by recalling and mentioning it. One of the important factors that give a team of relief workers an advantage over individual relief workers is the amount and diversity of relevant information held by the team due to its members' differing roles, responsibilities, training and experience. The team therefore is more likely to make informed and high quality decisions. However, in order to utilize their informational resources, team members must discuss and exchange them. Moreover, the categorization of information in the pool in accordance with the preferences of the various relief workers in diverse, cross-functional or distributed teams is a major challenge.

### 3.6.6   Concerns regarding network-based information management

Like any form of coordination, network based information management has it weaknesses that can raise concerns amongst stakeholders. In general, weaknesses such as low transparency, instability and the need for trust have been discussed exhaustively in previous work (e.g., Meuleman, 2008; Meyer & Baltes, 2003). Barnett (1999), and later Groh (2006) have outlined major concerns specifically on netcentricity in warfare, including "ignoring the human dimension" and the "overemphasis on technology". For the domain of disaster management, we postulate three major concerns regarding the (re)design of information system architectures in accordance with the netcentric approach.

The first concern is the threat of information overload that may overcome relief workers when they are able to receive information from a large number of network nodes (i.e., other relief workers and sensors). Here, information overload refers to "a cascade of data that exceeds the finite limits of information that can be processed and acted upon by a human being in a stressful and complex multitasking environment" (Stanovich, 2006). In existing hierarchical information architectures, information overload is mentioned as a problem for relief workers (e.g., Atoji, et al., 2000; Jenvald, et al., 2001; Manoj & Hubenko, 2007). Yet, we are concerned that having a far larger number of nodes participate in the information coordination process as dictated by netcentric coordination, information overload may occur more often than is the case with hierarchical coordination. A network of nodes is generally incapable of deciding and semantically filtering who needs what and when (Atoji, et al., 2004). In addition, when each individual relief worker is able to access to databases directly (instead of querying information via the control room or other agency), the tasks of discovering and filtering information from a large dataset may even increase the time needed to access relevant information. The change of distraction created by peripheral and irrelevant information is high and often has the effect of slowing down the decision-making process, as relief workers must process large amounts of obfuscating and sometimes contradicting information. Moreover, some nodes in the network may actually reduce the overall quality of the information in the network, for instance when contributing information of low quality (e.g., outdated, irrelevant or incorrect information). Therefore, information overload may not only delay the relief worker in making timely and effective decisions, it may also make it difficult for the relief worker to filter the right, high quality information from noise.

The second concern regarding netcentric information coordination is the dilution of decision-making and responsibility boundaries (an advantage of hierarchical coordination) when every relief worker has access to all information in the network. This means that relief agency commanders (strategic echelon) may interfere in decisions and actions on the operational level of response, just because the commanders think they know what is happening on the field. As observed by Stanovich (2006), the availability of such a plethora of near-real time information often creates the false impression among commanders that they have the same solid and accurate grasp of conditions and situational awareness as the local responders that deal with the incident at the scene.

The third concern is that of bottom up 'renegade freelancing'. Renegade freelancing is generally defined as 'illegitimate improvisation', which is not working toward the goals of strategic level commanders (Mendonca, Pina e Cunha, Kavo-Oja, & Ruff, 2004). Stanovich (2006) explains that freelancing is less of a problem in hierarchical settings where subordinates receive piecewise information (e.g., status information, decisions and instructions). In this context, freelancing due to the availability of the 'big picture' or shared situational overview can be considered as a deviation from higher intent that is both unpredictable and unexpected, and such activity presents serious problems to a unified response effort. Even though freelancing can also occur in hierarchy-based information systems, the self-synchronization capabilities in netcentric environments can encourage its occurrence and amplify its impact in the PSN.

## 3.7 Summary

This chapter presents our knowledge base and is the result of the investigation of two research questions (1a), *what are useful and tested instruments provided in the literature for studying information quality and system quality in public safety networks?* and 1b, *what pathways are provided in coordination theory and netcentric operations theory for assuring IQ and SQ in public safety networks?* Asking both questions is an important step in our design science approach since it allows us to prepare for empirical data collection and the synthesis of design principles for assuring IQ and SQ. We reflect on the answers in the conclusions chapter (Chapter 10).

The first part of Chapter 3 presents items for assessing IQ and SQ during disaster response. These items are included in surveys that we later used to measure the perceived levels of IQ and SQ among relief workers (see Chapter 4). The second part of this chapter elaborates on seven pathways derived from two kernel theories that help synthesize design principles for assuring IQ and SQ. The pathways provided in coordination theory are boundary spanning, orchestration, advance structuring, and dynamic adjustment. We discuss the translation of pathways and ideas presented in this chapter into testable principles in Chapter 6.

# 4 Empirical foundation: exploring three public safety networks

*"In theory, there is no difference between theory and practice. But in practice, there is."*

\- Yogi Berra (Baseball player)

## *4.1 Introduction*

The previous chapter dealt with several information quality (IQ) and system quality (SQ) issues and discussed some theoretical pathways for assuring IQ and SQ. As a progression of thoughts within a theory, these pathways still required further understanding of the context of use (multi-agency information management) before we could move on towards the synthesis of design principles. This chapter reports on the third phase of this research, which we consider as our empirical foundation since it provides an in depth analysis of multi-agency information management in public safety networks (PSNs). The construction of this empirical foundation was led by two research questions: *2a: How do relief agencies manage information during disaster response?,* and 2b: *Considering the various information system architectures in practice, what level of IQ and SQ do these architectures assure for relief workers during disaster response?*

In search of answers, we studied information management practices and IT applications in three different PSNs in the Netherlands. In light of RQ2b, we have also measured the resulting IQ and SQ for relief workers managing information by means of a specific information system. Each field study allowed us to investigate different information system architecture and their respective effects on the IQ and SQ for relief workers. In the first field study in the Port of Rotterdam, relief workers used a single, echelon expanding information technology (IT) application for information management purposes. In the second field study in Gelderland, relief workers used four IT applications for information management purposes. In the third field study in Delft, relief workers used 'whiteboards' for information management purposes instead of any particular IT application.

As discussed in chapter two, we conducted the field studies using a combination of four research instruments. Firstly, we observed relief workers, IT applications and information management practices during disaster response exercises. Here, observation refers to the on-site note taking based on a predefined observation protocol. Whenever physically possible (i.e., when space was available for us in training rooms), we observed in teams of two or three. Secondly, we examined several documents related to the disaster response exercise, including the exercise script, events, and roles (prior to the exercises). Thirdly, we administered surveys after each observed disaster response exercise in order to measure the level of IQ and SQ perceived by the respective relief workers. These surveys include empirically tested items for assessing IQ and SQ. Appendix-D provides an overview of the survey items used. Finally, during and directly after the exercises, we conducted ad-hoc, opportunistic interviews with relief workers, for instance requesting them to

explain the perceived IQ and SQ problems in more detail (see chapter 2 for more detail on the field study approach). This chapter elaborates on the general structure of PSNs in the Netherlands. This elaboration is a necessary prelude to the field study data. Then, this chapter presents the qualitative and quantitative data collected during each of the field studies. This chapter concludes with some cross-field study findings. Parts of the chapter were published in Bharosa et al. (2007), Bharosa et al. (2009), Bharosa et al. (2009), Bharosa et al. (2010), Bharosa & Janssen (2010), and Lee, Bharosa et al. (2010).

## 4.2 Background on public safety networks in the Netherlands

Policy makers in the Netherlands have arranged the procedures and configurations of PSNs in the act 'Wet Veiligheidsregio's. The act as passed on February 11, 2010 resulting from the Dutch Parliament's objective to improve the administrative and operational strength of PSNs. To date, the majority of municipalities have not yet organized their PSN in accordance to this act. However, since many of the municipalities are in the process of transforming their PSNs in accordance to this act, we take the prescriptions of this act as baseline in this dissertation.

The main idea underlying this act was that although safety eminently is a local responsibility, many municipalities are too small and possess insufficient resources to manage a disaster. By joining up the fire service, medical services and police departments on a regional level, this act aims to increase the strength, but also unity, clarity and simplicity of PSNs. When we focus on disaster response, the Wet Veiligheidsregio's dictates the activation of three echelons of response: the strategic echelon, the tactical echelon, and the operational echelon. Each echelon can include on or more single agency and multi-agency response teams. These echelons are activated in a hierarchical manner (first operational, then tactical and then strategic) depending on the severity of the disaster. The process of activation is predefined in the Gecoördineerde Regionale Incidentbestrijdings Procedure (GRIP) procedure. The GRIP levels indicate the severity and span of the disaster and can range from level 0 to level 4, see Table 4-1. .

### Table 4-1: Disaster severities and dictated response echelons

| Coordination alarm | Span of disaster effects | Activated response teams |
|---|---|---|
| GRIP 0 | Normal daily operations (e.g., small fire, traffic accidents) | -Motor hood meeting |
| GRIP 1 | Cause repression (e.g., medium-large fires, public shooting) | -Commando Place Incident Team (COPI) |
| GRIP 2 | Cause and effect repression (e.g., gas leaks, oil spills) | -COPI<br>-Regional Operational Team (ROT) |
| GRIP 3 | Harm to the well-being of large populations of the society (e.g., floods, toxic gas clouds) | -COPI<br>-ROT<br>-Municipality Policy Team (GVS) |
| GRIP 4 | Hazards beyond one municipality with changes of resource scarceness (e.g., airplane crash, terrorist attacks) | -COPI<br>-ROT<br>-GVS<br>-Regional Policy team (RBT) |

Level 0 represents (routine) incidents requiring no collective decision-making between responding organizations. These are normal accidents that can be handled by a single organization, for instance a small traffic accident. GRIP level 1 events entail small scale disaster requiring collaboration between multiple stakeholders. GRIP level 2 suggests regional cooperation and the strategic repression of the source of the disaster. The Wet Veiligheidsregio's considers GRIP levels 3 and 4 as large-scale disasters in which the municipality majors are required to take strategic decisions. Starting from GRIP 1, different decision-making teams are activated. Each decision-making team has a different focus in the overall response process. The ROT for instance focuses on strategic issues, such as the mitigation of the source of the disaster. On the other hand, the COPI decides upon more immediate (tactical) issues, for instance evacuating victims and repressing effects. In doing so, the COPI members also consider/follow the strategies formulated by their superiors on the REGOT level. The operational level (the actual first responders) execute the tactics from the COPI level. The GRIP level is set by the highest commanding level at the time. For instance, if a GRIP 1 situation cannot be repressed by the Commando Place Incident Team (COPI), this team's leader can decide to escalate the situation to a GRIP 2, in which the Regional Operational Team (ROT) will get the highest decision making responsibility. When there is a change to GRIP 3, teams such the Municipal Safety Team (GVS) are activated. As leader of the GVS, the Mayor is informed by the leader of the ROT, who in turn is informed by the COPI leader. As subordinates, the second in command officers should provide information to their commanding officers.

Considering the GRIP structure, we conclude that the formation of PSNs rest firmly upon the hierarchical command and control based form of coordination, which we have discussed in chapter four. Similar to for instance the structures in Spain (O'Riordan, 2004), London (Fitzgerald & Russo, 2005) and the United States (Bigley & Roberts, 2001), the GRIP structure dictates a authority based activation of decision making and information management during disaster response. Having elaborated on this general coordination structure for PSNs in the Netherlands, we proceed by discussing our field study findings next.

## 4.3    Field study #1: The Port of Rotterdam

Amongst the world's largest seaports, the Port of Rotterdam (PoR) is about 10500 ha (see www.portofrotterdam.com). Over sixteen thousand companies operate in this major harbor area. Every day, companies import, store, transfer and export enormous quantities of chemicals and other hazardous. Storing and transferring these dangerous materials implies potential catastrophes for humans and infrastructure in the area. Obviously, when a disaster unfolds in such a large and hazard-prone area, consequences can only repressed by efficient and effective disaster management. To ensure local disaster management organizations are prepared, the Veiligheidsregio Rotterdam-Rijnmond (VRR) stimulates (e.g., through funding and accommodation) recurrent disaster management exercises in the port area. Annually, the VRR organizes three types of multi-agency exercises for relief workers in the Rotterdam-Rijnmond PSN, that is:

1.  *Exercises for the strategic response echelon.* These exercises focus on training either the Gemeentelijke Veiligheidsstaf (Municipal Safety Board) or the Regionale Beleids Team (Regional Policy Team). The participants on

this echelon include relief agency commanders, including the Mayor of the municipality the exercise is conducted in. In total, VRR organizes 28 exercises of this type each year, which is in accordance to the number of municipalities in the Rotterdam-Rijnmond region. This type of exercise takes around four hours and includes seven to ten participants (depending on the availability of the relief agency commanders).

2. *Exercises for the tactical response echelon.* These exercises focus on training the Commando Plaats Incident Team (Commando Place Incident Team). The participants on this echelon include the second and third persons in command of the various relief agencies. This type of exercise is of a larger scale compared to the exercises for the strategic echelon. As such, these exercises demand more human and financial resources than exercises for the strategic response echelon. Each year, VRR organizes eight exercises of this type. Compared to the strategic echelon, the exercises for this echelon require more trainers and resources, for instance a COPI team at the exercise location. This type of exercise takes around four hours and includes ten to fifteen participants (depending on the availability of the relief agency commanders). The trainers manage to organize at least two of these exercises each day, training a total of twenty to thirty different relief workers each day.

3. *Exercises for the operational echelon.* These exercises focus on the first responders to disaster situations. The participants on this echelon include the field unit officers of the various relief agencies. This type of exercise is of a larger scale compared to the exercises for the strategic echelon and tactical echelons. As such, these exercises demand more human and financial resources than exercises for the strategic and tactical echelons. VRR organizes no more than two of these exercises each year.

During the three types of exercises mentioned above, the trainers simulate the remaining echelons on paper. This means that, for instance, during a tactical echelon exercise, relief workers from the strategic and the operational echelon are not present. The decisions and actions taken by the other echelons are brought into the exercise in the form of messages.

Since the objective of this research project is to develop and evaluate design principles that assure IQ and SQ for multi-agency disaster response teams, we focused on studying strategic and tactical echelon exercises. Another reason for focusing on the strategic and tactical level exercises is the opportunity for relief agency commanders to employ information systems in their practices. These echelons are activated in case of medium to large-scale emergencies (see figure 4.1). Since the operational echelon exercises often only employ radio or mobile communications and do not manage information using IT applications, these exercises were outside the scope of our research.

Table 4-2 outlines the training exercises we observed as part of our field study in the Port of Rotterdam.

**Table 4-2: Initial observations in Rotterdam-Rijnmond**

| Date | Municipality | Echelon trained | Number of observations |
|------|-------------|-----------------|------------------------|
| 24/11/2006 | Vlaardingen | Tactical/COPI | 3 observers x 2 observations |
| 01/12/2006 | Vlaardingen | Tactical/COPI | 2 observers x 2 observations |
| 02/05/2007 | Koolhaven | Strategic/ROT | 2 observers x 1 observation |
| 27/11/2007 | Vlaardingen | Tactical/COPI | 1 observer x 1 observation |
| 15/04/2008 | Rotterdam Airport | Operational | 4 observers x 1 observation |

Table 4-2 outlines the initial training exercises that we observed in the Rotterdam-Rijnmond field study. The objective of these preliminary field observations was to gain understanding of how multi-agency information management takes place in practice. This understanding was also needed in order to develop understandable and context specific data collection instruments (i.e., observation protocol and surveys). We tried to observe every exercise in teams of two to three persons, allowing us to capture a wider range of the exercise and corroborate our observations. In addition, most of the COPI exercises included two round of exercises one a single day, allowing for two observations per observer. Different relief workers participated during the different exercises. The organizers and exercise facilitators were the same throughout the different exercises. During the tactical echelon exercises, the organizers used two different scenarios: A gas leak (morning session) and an explosion on a cruise ship (afternoon session). During the strategic echelon exercise, the organizers used a slightly different scenario involving the collision of two ships. The operational level exercise involved an airplane crash at the Rotterdam Airport. The following table provides an overview of these scenarios.

**Table 4-3: Examples of scenarios exercised in Rotterdam-Rijnmond**

|  | Gas leek | Explosion on a cruise ship | Collision of two ships | Airplane crash landing |
|--|----------|----------------------------|------------------------|------------------------|
| Description | Disturbance of public order combined with a possible toxic spill producing a gas cloud at Unilever premises | An explosion on an unknown ship deck location, members of the royal family are on board and require evacuated | Two ships collide in a difficult to pinpoint location. One ship was an oil tanker, the other included chemical cargo | A medium sized aircraft signals a failing motor and crashes during landing |
| Disaster elements | Toxic gas, possible hostile people on premises, evacuation | Fire, VIPs, surrounding ships and inhabited areas | Inconsistent ship locations, potential oil spill, unknown chemicals | Unknown number of passengers on board, collateral damage |

Table 4-3 outlines the disaster scenarios that trainers used during multi-agency disaster response in the Rotterdam-Rijnmond area. Each scenario started as a GRIP level 1 disaster, triggering the activation of a multi-agency COPI team. Ultimately, each exercise reached GRIP level 3, avoiding the activation of a nationwide disaster coordination team. The exercises included events and uncertainties

comparable to each other. The following subsections elaborate on the actors, information flows, and IT applications used during the observed exercises. While attempting to give a general impression on these aspects, we sometimes give exercise specific examples from our observations in order to be explicit on our findings. The following figure outlines a typical configuration of actors during one of the observed COPI and GVS exercises.

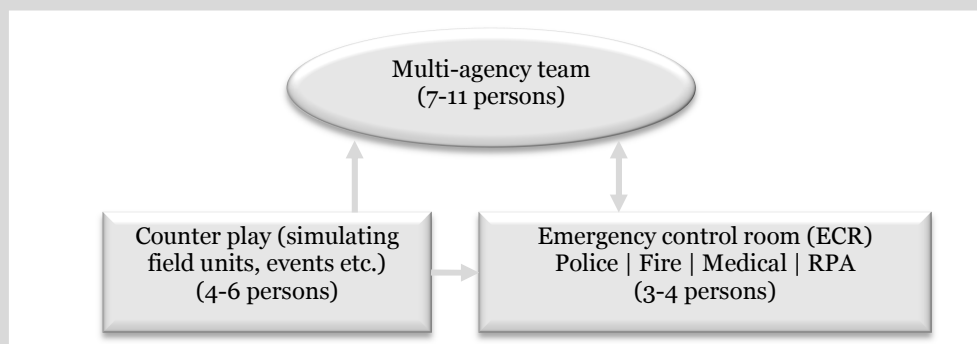**Figure 4-1: Typical exercise configuration**



Figure 4-1 illustrates the choreography of the multi-agency teams (i.e., GVS, COPI and ROT) and the number of actors during such exercise. The exact number of participant can differ for each disaster scenario and the availability of the relief workers on that particular day. The following subsection provides a more detailed description on the participating actors.

### 4.3.1    Actors and coordination structure

Multi-agency disaster response requires several public and private organizations to respond in concert. Collective learning and adaptation of partnerships in dynamic context depends upon valid and reliable information and timely feedback among organizations In accordance with the GRIP procedure mentioned in section 4.2, representatives from both public and private organizations collaborate and share information in multi-agency teams. In accordance with the disaster management handbook of the VRR, the training exercises involved multi-agency teams with a fixed and optional set of agencies. The fixed set includes representatives of the fire department, police department and ambulance services. In the Rotterdam-Rijnmond area, the Rotterdam Port Authority (RPA) is also part of the fixed configuration of actors.
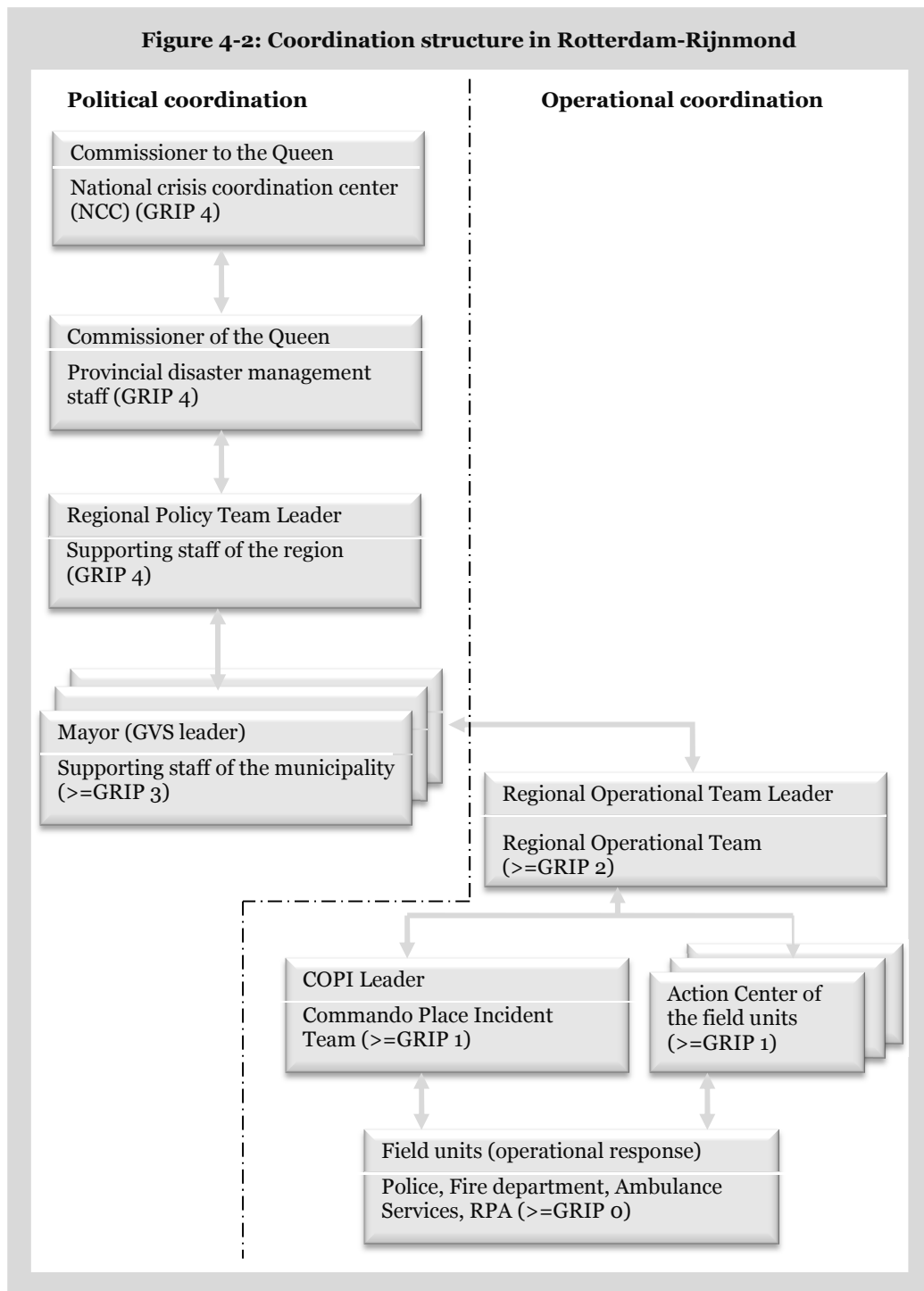
The optional/variable list of actors consists of more specialized relief workers (i.e., hazardous materials experts and company representatives) depending on the disaster at hand. Examples of optional representatives in the multi-agency team include a Supply Manager of Unilever R&D and a fleet manager of a Cruise Ship Company (Cruise ship explosion scenario). The following table outlines the roles and actors we observed across the training exercises in the Rotterdam-Rijnmond field study.

**Table 4-4: List of roles and actors in the multi-agency decision-making teams**

| Role(s) | Actor in GVS | Actor in COPI |
|---|---|---|
| Process leader, team captain, communication to external parties | Mayor | Commander of the Fire department |
| Allocation of police resources, focus on law and order, Information manager | Chief of police | Second in command of the police department |
| Allocation of fire department resources, focus on mitigation of fire and evacuation of victims | Chief of fire department | Second in command of the fire department |
| Allocation of ambulance services, focus on the treatment of victims on the spot and transport to nearby hospitals | Chief of ambulance services | Second in command of the ambulance |
| Information manager: 1) receiver of external situation reports, 2) generation of internal team situation reports, 3) projection of situation reports | Secretary of the Mayor | Police officer |
| Provision of municipal plans and resources pertaining risk and crisis management | Municipal emergency coordinator | Municipal emergency officer |
| Press officer: information sharing to the press | Police officer | Police officer |
| Support in terms of legal affairs and provide advice on legislation and procedures | Department of Justice officer | - |

The roles in table 4-4 are not substitutable or interchangeable with each other, as each role represents a specific set of resources and responsibilities. The following figure visualizes one possible coordination structure that comprises the aforementioned roles. The arrows represent the information flows between the various teams.

Note that figure 4-2 rests upon our observations of the coordination structure in the Rotterdam-Rijnmond Safety Region. Other safety regions are still in the process of redesigning their coordination structure in line with the GRIP prescription in the Wet Veiligheidsregio's. One institution not included in figure 4-2 is the supporting Emergency Response Center (ERC), an organization similar to the Public Safety Answering Point in the USA (a.k.a. 9-1-1 emergency dispatch center), because this center has a facilitating rather than a hierarchical role. Each ECC acts as an information center for just one of the relief agencies. For the case of the Rotterdam Harbor, the ERCs of the Police, Fire brigade, GHOR and RPA are physically collocated on the same floor in the World Port Center. This should allow for more information sharing, at least on the level of the control rooms. In reality, the ERCs of each column support their own organization on all levels of decision-making. On the other hand, each of the ERC's gets their information from multiple sources, including interaction with the other levels.

**Figure 4-2: Coordination structure in Rotterdam-Rijnmond**

**Political coordination**

| Commissioner to the Queen |
| National crisis coordination center (NCC) (GRIP 4) |

| Commissioner of the Queen |
| Provincial disaster management staff (GRIP 4) |

| Regional Policy Team Leader |
| Supporting staff of the region (GRIP 4) |

| Mayor (GVS leader) |
| Supporting staff of the municipality (>=GRIP 3) |

**Operational coordination**

| Regional Operational Team Leader |
| Regional Operational Team (>=GRIP 2) |

| COPI Leader |
| Commando Place Incident Team (>=GRIP 1) |

| Action Center of the field units (>=GRIP 1) |

| Field units (operational response) |
| Police, Fire department, Ambulance Services, RPA (>=GRIP 0) |

The coordination structure in Figure 4-2 dictated all of the exercises in the Rotterdam-Rijnmond field studies. The structure complies with the recently introduced law on the Safety regions discussed in section 4.2. The fixed (regular) relief agencies involved in Rotterdam field studies included the police departments, the fire departments, the RPA, municipality officials, and the ambulance services in the region. The support staff in each decision making team consisted of subordinate officials with tasks such as information management, public relations and control room communication. The action centers of the field units are usually hosted in on-site physical containers, similar to the ones used by COPI. These action centers are also known as the 'low control' or action centers of the three major relief agencies (police, fire department and ambulance services) and serve as control rooms for the respective agency commanders after each COPI meeting.

Depending on the scenario trained, the multi-agency teams also include roles such as chemical/toxic advisers, representatives of nearby businesses, public infrastructure managers, and representatives of shipping/cargo companies in the region. During these meetings, the representatives of the various agencies take turn in sharing the information they have with the team. The team functions as a verbal pool of information. The following section elaborates on how information is managed within such teams.

### 4.3.2 Information management practices

Rotterdam-Rijnmond is one of the first safety regions in the Netherlands that employs information managers for sharing situation reports between the multi-agency teams (ROT, GVS and COPI). When we conducted the field studies, the role of information manager (IM) was still very basic: taking notes of the information shared in the decision-making rounds and sending these as situation reports to the other multi-agency teams. The role of IM was usually fulfilled by a police officer (in the COPI and ROT) or personal assistant of the Mayor (in the GVS) who had received some basic instructions on using CEDRIC, an application used form intra-team information sharing during disaster response. In 2008, CEDRIC replaced Multi-team for intra-agency information sharing. These applications provide a web-based template for sending situation reports and are operate by an Information Manager (IM). We elaborate on these applications in section 4.3.4.

Using the observation protocol (Appendix B), we found that some information needs and flows were common for each of the observed exercises, while other information needs only held for a specific exercise. Note that we did not study the various types of information that relief agencies need during disaster response. In order to develop such a categorization, we would have to study a wider range of disasters than we do in this dissertation. Instead, we have included a categorization provided in the ACIR investigation (ACIR, 2005) in our observation protocol. The following table outlines some of the information objects that were collected and shared during the observed training exercises.

| Table 4-5: Generic information objects shared during Rotterdam field studies | | |
|---|---|---|
| **Category** | **Description** | **Examples** |
| Object/source information | Information pertaining the source of a disaster, including the cause of events | Source of a fire, source of an explosion, size of a building |
| Geographic information | One of the first decisions relief agencies make is to establish the disaster source and affect area | Coordinates of a building, buildings in the area, navigation routes |
| Victim and bystander information | One of the priorities of relief workers is to rescue victims and secure the area. In order to do so, relief workers need information (e.g., numbers, location, state) on victims and bystanders in the area | Number of deaths, number of wounded, number of bystanders |
| Hazards and risks information | The agencies responding to disasters cope with "shared risk." This information is necessary in order to take precautions, for instance, scale up the GRIP level | Amount of oil stored in tanks, chemicals in a factory, toxic level of a leaked gas |
| Weather (meteo) information | Depending on the type of disaster, information on the weather conditions in the area can influence both the disaster and the response process | Wind speed, direction and strength of the wind, humidity, changes of rain |
| Plan-information | Often, relief workers want to know which plans (e.g., etc.) were already available. Plans often form the basis of deploying resources during the response process | Factory safety procedures, contingency plans, guidelines, safety regulations, evacuation plans |
| Capacity information | Information on the human and physical resourced available, needed or already at the disaster location | Number of officers, fire trucks with foam tanks |

CoPI teams collaborate in face-to-face settings supported by relatively sparse access to information sources. The main networks used are radio Porto phones and mobile phone networks that connect the different members of the team to their respective command and control centers. This is vulnerable and inefficient, access to information sources directly would allow for more rapid retrieval. Moreover, the team leader often requested the team members to switch off all forms of voice communication during team meetings. This precaution avoids too much distraction and interruption of team meetings.

Besides the information needs listed above, we observed the need for varying information during the disaster exercises in the Rotterdam harbor. Each scenario exercised brought its own disaster response challenges and generated different information needs in the multi-agency teams. We listed some of the main specific information needs in the following table.

| Table 4-6: Scenario specific information needs | |
|---|---|
| **Scenario** | **Specific Information needs** |
| Gas Leak | -Information on the people leading the unanticipated demonstration outside the Unilever building.<br>-Information on the chemicals and their explosiveness stored in the factory<br>-Information on the barrels outside the area with presumed dangerous chemical material in the area |
| Cruise Ship | -Traffic information in the area as news on the royal family at the spot attracted much attention.<br>-Update on the status of the evacuation of royal family<br>-Information on the blueprint of the ship and the location of the explosion.<br>-Information on surrounding hotels and hospitals in the area in order to allocate the cruise ship passengers. |
| Ship collision | -Two different coordinates of the ships were received in the collocated emergency control rooms: which one was correct? |
| | -Is there any oil spilled? How much and where? |
| | -The details on the chemicals located in one of the ships: "are they flammable or toxic?" |
| | -How many members did the crews of both ships contain? |

The focus of a CoPI team is to construct a joint operational picture and to establish appropriate actions according to the constructed operational picture. The information manager is responsible for sharing the constructed operational picture with the other echelons (in case these are activated). Each team member has a mobile phone and some, e.g., chemical advisors carry books with them. The joint operational picture is codified in flip-overs attached to a wall. Detailed maps of the area are available in the local command center. Sometimes, team leaders post a list of actions that commanders should complete after the meeting. When resuming the meeting, some of the leaders systematically check mark the actions that were completed. Figure 4-3 illustrates the IS architecture observed during the exercises in Rotterdam-Rijnmond. This figure shows the information flows between the various teams and ECC during disaster response. This figure also depicts the information sources available to each team.

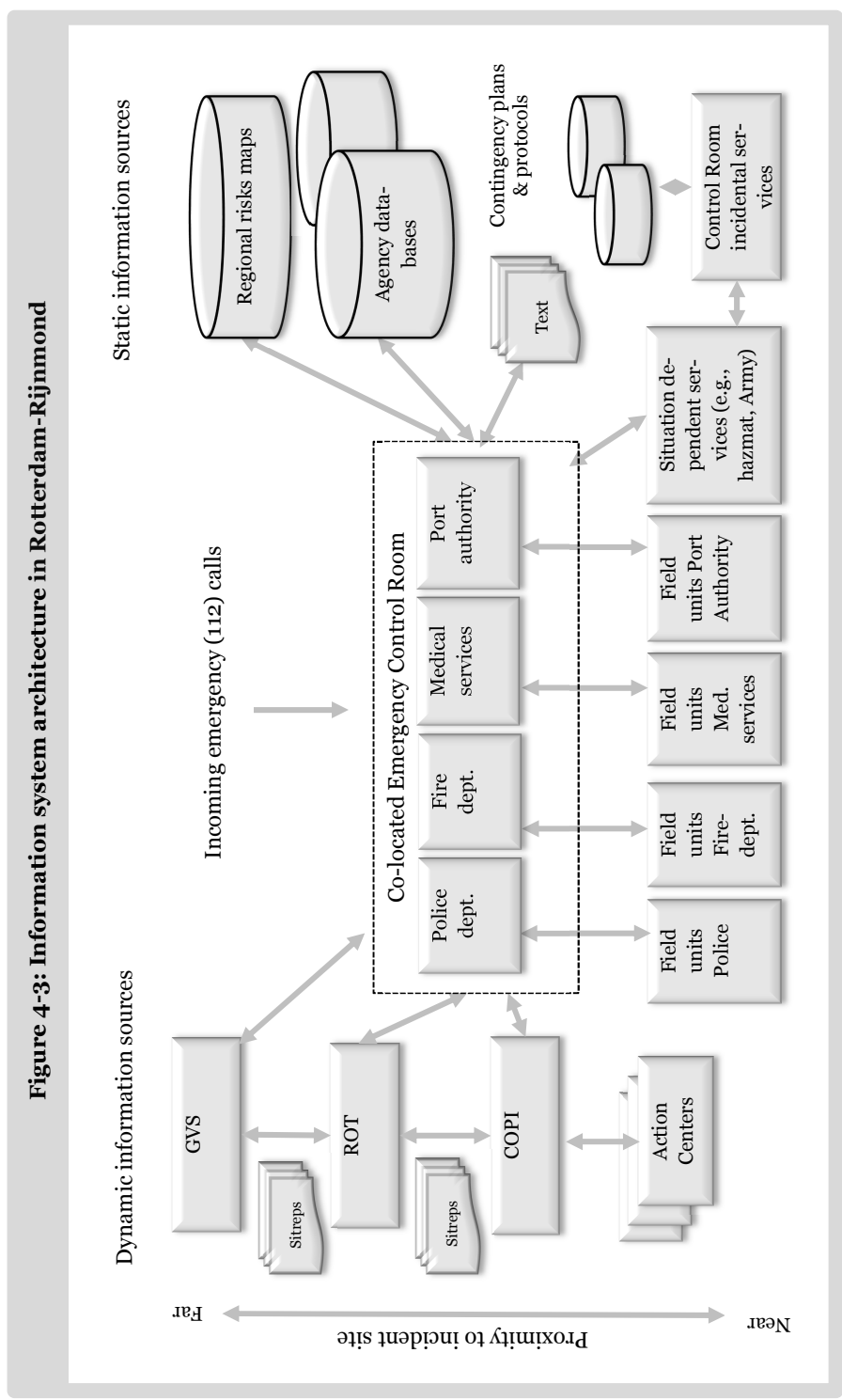**Figure 4-3: Information system architecture in Rotterdam-Rijnmond**

Figure 4-3 illustrates the IS architecture observed during the exercises in Rotterdam-Rijnmond. The ECC in the Rotterdam-Rijnmond region was among the first to combine the control stations of the police department, fire brigade, ambulance services and harbor police (RPA) in the same physical location (World Port Center). In spite of this, there is still no formal arrangement with regard to the coordination of cross-agency information flows in the control room. As a result, we found that little information was actually shared between the co-located ECC even though the control room facilities and infrastructure were being shared.

### 4.3.3 Multi-agency information management applications

Alongside the agency-specific IT applications, one IT application was dedicated for multi-agency information sharing between the autonomous agencies. This IT application is known as CEDRIC. CEDRIC is a Web-based communication tool that allows information managers to share situation reports about the disaster (in a messaging or e-mail style) in such a way that members of different echelons if activated can view it (COPI, ROT, GVS, GBT). In essence, CEDRIC is an extended mailing application that allows relief workers to e-mail situation reports across agencies. As such, the main functionality of this application is the generation, exchange and storage of situation reports across multiple teams. Other functionalities (some added in later versions) include document storage, search (in the internal databases and phonebook), and area plot (map) viewing. Figure 4-4 illustrates the CEDRIC user interface.

**Figure 4-4: Screenshot of the CEDRIC used in Rotterdam-Rijnmond**

The screenshot illustrates a situation report in the CEDRIC application. This report can be printed and shared with other relief workers when necessary. Architects have organized CEDRIC similar to Microsoft Outlook with the active navigation panels on the left and the main panel at the center of the screen. On the left hand side of the screen, some of the functionalities of CEDRIC are displayed. The information manager is the only operator of the CEDRIC application in each multi-agency team. The purpose of the CEDRIC is to allow information managers to access, generate, store and send documents and messages across multiple teams on the strategic and tactical echelons. This application started bottom up as a pilot initiative of four municipalities surrounding the Harbor region. In fact, this application functions as a message and document library with mailing functionalities between the police, fire department, and medical services. This application not only allows situation report exchange, but also document exchange (like an e-mail system). An address book of participants (roles) is already part of the system and it is possible to send individual, group or broadcast messages. In latter versions of CEDRIC (version 2.0), a geographic plotting functionality was integrated, allowing the IM to view a dynamic map of the Harbor area.

The connection between the client (IM with touch screen laptop) and the server was established using a mobile connect UMTS data card. The connection allowed for a variable internet speed, varying between a maximum of 384 Kbps downlink, and 64 Kbps uplink. This connection was not always stable. In case of failure, the IM was unable to continue writing a situation report. We observed that some more experienced IM used Microsoft Word as a workaround for the connectivity problem. First, the IM typed a situation report in Microsoft Word, which did not need an internet connection. When they were done, they simply copy pasted their text into the appropriate fields of the CEDRIC situation report template.

### 4.3.4 Qualitative data: observed IQ and SQ issues

During the Rotterdam field studies, we observed several recurring IQ and SQ issues. For instance, the exact location of the disaster was often a point of discussion and confusion within the multi-agency teams. The commanders of the relief agencies often get the coordinates of the location via their agency operator in the ECC. We even observed two situations in which the commanders of the fire brigade, police, and medical services all had three inconsistent coordinates of the disaster. Consequently, the information manager was forced to mention all three locations in the situation report. This issue was resolved by requesting the commanders to double-check the coordinates with their subordinates after the meeting.

Another often-occurring IQ issue is on the number of casualties. While the casualty count is something the commander of the ambulance services should be aware, we observed several cases in which the count was unavailable, outdated and incorrect. Regarding the SQ, the most occurring issue we observed was the high response time, defined as the delay between an information request and response. This was often the case for information that was beyond the reach of the information manager or the ECC. Examples include information about hazardous materials stored in buildings, the cargo stored in specific containers and the blueprint of the area or ship. Occasionally we observed some infrastructure reliability issues causing CEDRIC to 'hang' and freeze the situation report typed by the information manager. A workaround used for this is typing the situation report in Microsoft Word and copy pasting the text in the online situation reporting software.

As stated in Chapter 2, the surveys also contained open questions regarding IQ and SQ experienced during the exercise. The following table outlines some of the translated examples of IQ and SQ issues provided by relief workers.

**Table 4-7: IQ and SQ issues experienced by the relief workers**

| Statements provided by the relief workers | IQ dimension | SQ dimension |
|---|---|---|
| "there was no timely information sharing about affected area and dangers, including hazardous materials and victims, we did not look further for missing persons and just assumed that they would be on the ship" | Timeliness | Accessibility, Response time |
| "in the second exercise we did not know where the rescue units were stationed" | Completeness | Accessibility |
| "regarding the ship, we did not know about its size, type, structure etc." | Completeness | Accessibility |
| "it often took too long before we found out which hazardous materials we had to deal with" | Timeliness | Response time |
| "the exact time at which the wind would turn against us was unavailable" (scenario alpha)" | Completeness | Accessibility |
| "there were different location maps circulating, which led to confusion about the ship location and affected area. After 3 meetings, we found the right location" | Consistency | Interoperability |
| "for the common operational picture, it would be nice if we could project a graphical image of the incident starting the first COPI meeting. This would help forming the first COPI team" | Format | Interoperability |
| "we did not receive information about the hazardous materials on time" | Completeness | Response time |
| "all information should be verified before it is put into CEDRIC" | Correctness | - |
| "in most situations information access problems occurred, However, I can not specify one immediately" | - | Accessibility |
| "rapid escalation of the incident could barely be shared with other agencies before the activation of the COPI" | Relevancy | Interoperability |

Table 4-7 lists some of the IQ and SQ issues experienced by the relief workers themselves. Some of these are more related to CEDRIC and the information manager than others. The next section discusses the overall scores for the IQ and SQ as experienced by the relief workers.

### 4.3.5 Quantitative data: survey findings

While we used the first six series of exercises in Rotterdam-Rotterdam to obtain insights in the information system architecture and information management practices, we used the second round of exercises to survey relief workers on their perceived IQ and SQ during the exercise. The survey employed includes the items for assessing IQ and SQ that we have discussed in Chapter 3. An overview of survey items can be found in Appendix-D. Note that the exact survey sent out was adapted

to the context of the relief workers in each of the specific locations. Table 4-8 outlines the surveyed exercises in Rotterdam-Rijnmond.

**Table 4-8: Surveys Rotterdam-Rijnmond exercises**

| Date | Location/Municipality | Type of exercise | Completed surveys |
|---|---|---|---|
| 04/09/2008 | Ridderkerk a/d IJssel | Strategic/GVS | 8 out of 10 |
| 13/10/2008 | Westvoorne | Strategic/GVS | 3 out of 9 |
| 15/10/2008 | Maassluis | Strategic/GVS | 4 out of 9 |
| 18/10/2008 | Brielle | Strategic/GVS | 8 out of 11 |
| 23/10/2008 | Vlaardingen | Tactical/COPI | 15 out of 28 |
| 11/11/2008 | Krimpen a/d IJssel | Strategic/GVS | 6 out of 9 |
| 13/11/2008 | Landsingerland | Strategic/GVS | 4 out of 8 |
| 14/11/2008 | Vlaardingen | Tactical/COPI | 16 out of 28 |
| 19/11/2008 | Dirksland | Strategic/GVS | 6 out of 9 |
| 20/11/2008 | Bernisse | Strategic/GVS | 7 out of 10 |
| 27/11/2008 | Vlaardingen | Tactical/COPI | 14 out of 25 |
| 04/12/2008 | Vlaardingen | Tactical/COPI | 16 out of 24 |
| Total response | | | 107 out of 179 (59%) |

We administered the surveys using Net-Questionnaire (www.netq.nl), an online tool for distributing surveys. The list of participants provided by the trainers allowed us to prepare and send out a link to the online survey immediately after each exercise. We were able to reach a 59% response rate (after a reminder), which is relatively high for online surveys. However, when inspecting the data using SPSS 17.0 we found that almost one third of the competed surveys contained missing data on multiple items. There are several explanations for this, including that the surveys were too long, the online tool crashed or the relief workers were interrupted (or called on duty) during the time that they responding to the survey. We did not find any specific remarks in the 'remarks' area of the survey, leaving us with no



Figure 4-5: Sample description for the Rotterdam surveys
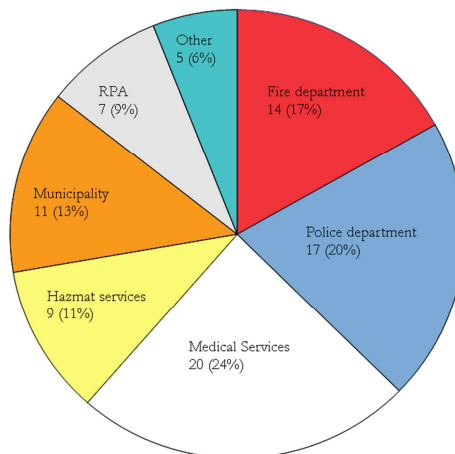
clear indication what caused the missing data. After list-wise deletion, the total number of useful surveys for data analysis was reduced to 83.

Figure 4-5 shows that the majority of the 83 respondents to our online survey were relief workers from the medical services. The second largest groups of respondents were police officers. The group of 'other' consists of respondents from the Department of Justice, National Army. The next subsection discusses how the data was prepared and analyzed.

### 4.3.5.1 Data preparation and reliability analysis

The data collected from the web surveys were prepared and analyzed in SPSS 17.0. The Netquestionaire tool provided us the data in a pre-structured format that we could import directly in SPSS. Since we used multiple items to measure a single construct, we were able to conduct a reliability analysis prior to calculating the average scores and standard deviations (discussed in the next section). Table 4-9 outlines the findings of the reliability analysis.

**Table 4-9: Reliability analysis for Rotterdam survey items**

| Dimension | IQ/SQ Items | Cronbach's α |
|---|---|---|
| IQ_TIMELINESS | IQ_TIMELINESS_A<br>IQ_TIMELINESS_B<br>IQ_TIMELINESS_C_REC | .898 |
| IQ_CORRECTNESS | IQ_CORRECTNESS_A<br>IQ_CORRECTNESS_B_REC (discarded)<br>IQ_CORRECTNESS_A | .689 |
| IQ_COMPLETENESS | IQ_COMPLETENESS_A<br>IQ_COMPLETENESS_B<br>IQ_COMPLETENESS_C | .892 |
| IQ_RELEVANCY | IQ_RELEVANCY_A<br>IQ_RELEVANCY_B<br>IQ_RELEVANCY_C | .843 |
| IQ_RELIABILITY | IQ_RELIABILITY_A<br>IQ_RELIABILITY_B<br>IQ_RELIABILITY_C_REC (discarded) | .873 |
| SQ_RESPONSETIME | SQ_RESPONSETIME_A<br>SQ_RESPONSETIME_B | .220 |
| SQ_ACCESSIBILITY | SQ_ACCESSIBILITY_A<br>SQ_ACCESSIBILITY_B<br>SQ_ACCESSIBILITY_C<br>SQ_ACCESSIBILITY_D | .812 |
| SQ_SATISFACTION | SQ_SATISFACTION_A<br>SQ_SATISFACTION_B | .761 |
| SQ_FLEXIBITY | SQ_FLEXIBITY_A<br>SQ_FLEXIBITY_B<br>SQ_FLEXIBITY_C (discarded) | .556 |
| SQ_RELIABILITY | SQ_RELIABILITY_A (discarded)<br>SQ_RELIABILITY_B_REC<br>SQ_RELIABILITY_C_REC | .637 |

Table 4-9 presents the values for the Cronbach's Alpha, which is a measure for the internal reliability of a scale used for each construct. Note that this table does not include the constructs that we measured using one item (i.e., IQ overload,

IQ consistency). In addition to the Cronbach's Alpha value for each construct, the SPSS Statistics Syntax editor provides some suggestions for enhancing the Cronbach's Alpha by discarding one or more items. The items we discarded in order to obtain a higher Cronbach's Alpha are labeled with 'discarded' in the table. George and Mallery (2003) suggest that the following norms for interpreting the Cronbach's Alpha coefficient: > 0.9 is considered: excellent; > 0.8: good; > 0.7: Acceptable; > 0.6: questionable; > 0.5: meager, and < 0.5: unacceptable. Note that these norms assume a large data set (over 100 cases), whereas our data set contains 83 cases. Considering the norms, the Cronbach's Alpha for SQ_RESPONSETIME is definitely unacceptable, pointing towards a low internal reliability for this construct. The second Cronbach's Alpha that raises some concerns about the items we used is the Cronbach's Alpha for the SQ_FLEXIBILITY (.556), which we interpret as meager, even when deleting SQ_FLEXIBILITY_C. The remaining constructs have an 'acceptable' or even 'good' Cronbach's Alpha (in some cases after one of the item scales is discarded). The following section discusses the IQ and SQ averages, after the items that reduced the scale reliability were discarded.

### 4.3.5.2  IQ and SQ averages

As part of the field study in Rotterdam-Rijnmond, we requested the participants of the training exercises to rate the IQ and SQ experienced during the exercise. Using three different questions (formulated as propositions) for each IQ and SQ dimension, we asked the relief workers to indicate the level of quality on a 7-point Likert-Scale. When analyzing the data, we were particularly interested in the average mean and standard deviation for each of the IQ and SQ dimensions. The following graph provides the scores for the different IQ dimensions throughout the field studies in Rotterdam-Rijnmond. Note that each IQ dimension was measured using three questions.



**Figure 4-6: Information quality assessment for the Rotterdam-Rijnmond field study (n=83)**
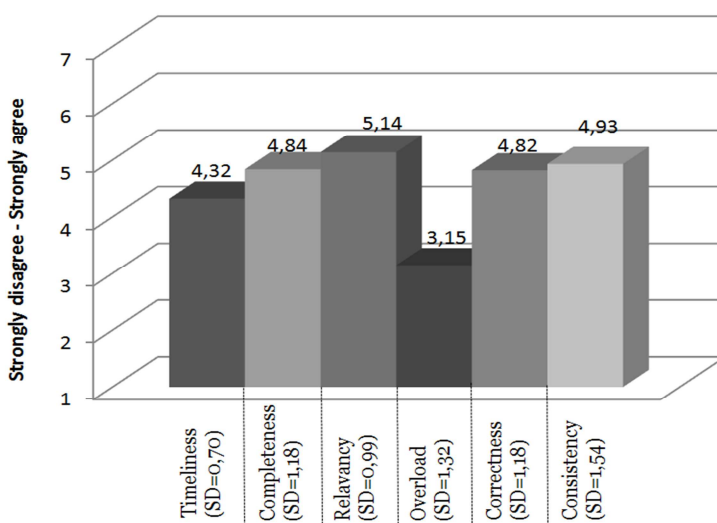
The average scores presented in the figure above indicate that the relief workers perceived the overall quality of information as 'moderate' with the exception of the understandability of information (low score). The highest score we can deduce from the data is that for the relevancy of information (5,14): relief workers perceived the information provided to them (either via the ECC or IM) as fairly relevant for their tasks. Figure 4-6 also shows that information overload (too much information) was not a problem for the relief workers, even though the standard deviation was over 1,3. The standard deviation of the consistency of information seems to be the largest from this data set (1,54), while the respondents seem to disagree less on the mean for the timeliness of information. The following figure outlines the average score for the information system quality in the Rotterdam-Rijnmond field study.

**Figure 4-7: System quality assessment for the Rotterdam-Rijnmond field study (n=83)**
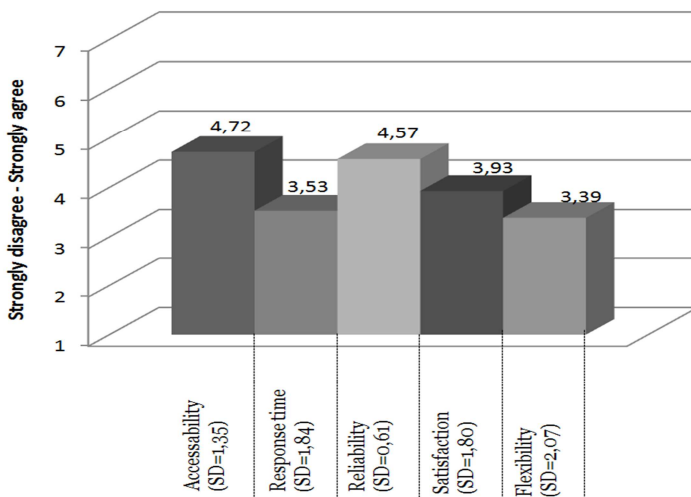


The average scores in Figure 4-7 indicate that there are some differences for the perceived system quality among the relief workers. While relief workers perceived the accessibility of information as moderate, the response time was rated relatively poor (3,53). This indicates that while information was generally available via the IM or ERC, it sometimes took too long before relief workers received this information. Note that the standard deviations for both the response time (1,84) and accessibility (1,35) dimensions are relatively high. Figure 4-7 indicates a relatively low score for the satisfaction with the information system.
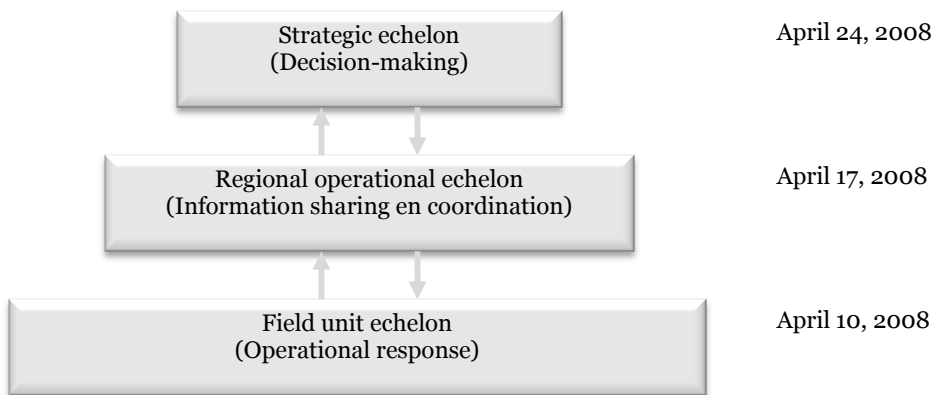
Note that the IM and ECC were included as elements of the information system in the questions provided to the relief workers. Generally, the surveyed relief workers were not satisfied about the performance of the IM and ECC in terms of information collection and sharing. Finally, relief workers find the flexibility of the information system to be relatively low (3,39), even though the standard deviation for this dimensions is very high (2,07). When we consider one of the propositions

presented to the relief workers on the flexibility of the information system (the information system also provided me with information that were beyond my regular information needs), we can conclude that the information system in Rotterdam-Rijnmond failed in this respect.

## 4.4   Field study #2: VIKING

The Gelderland-Zuid Safety Region in the Netherlands was our second field study. We observed three ROAR exercises of the VIKING program, cross-border collaboration between the Netherlands and Germany. These exercises aimed to prepare multiple relief agencies on both sides for a flood in the region. In contrast to the training exercises in the Rotterdam-Rijnmond field study, the ROAR program included three consecutive disaster response exercises, including the training of first responders (field units) echelon, the operational echelon and the strategic (policy) echelon. Figure 4-8 visualizes the exercise echelons we observed.

**Figure 4-8: Exercise echelons in the Gelderland field studies**

| | |
|---|---|
| Strategic echelon (Decision-making) | April 24, 2008 |
| Regional operational echelon (Information sharing en coordination) | April 17, 2008 |
| Field unit echelon (Operational response) | April 10, 2008 |

The studied exercises (labeled ROAR) took place in spring 2008 as a part of Program VIKING, an international flood/high-water management project between the Netherlands and Germany. Together the province of Gelderland (the Netherlands) and the province of Nordrhein-Westfalen (Germany) designed and hosted these exercises. The risk of major flooding is particularly high in two provinces where the Rhine River flows through Germany into the Netherlands. The explicit goals of the exercises, as formulated by the exercise leader, were to improve multi-agency collaboration between DM agencies on different echelons of response (i.e., strategic, tactical, and operational), information sharing between the Dutch and German DM agencies, information provisioning to the operational units during floods, and skills in using IS for flood control.

The exercise participants were required to respond to a disaster situation as specified in a scenario. Trainers had written the scenario in script format. Participants were stimulated to act via personalized (role specific) instructions and short

messages during the exercise. The scenario simulated a GRIP 4 level disaster, which is the highest-level disaster according to the Dutch classification system (see section 4.1). The scenario contained multiple incidents including dike breaks alongside the Rhine River and a shipwreck spilling unknown toxic chemicals into the river. Trainers underlined the level of uncertainty into the scenario by including an unknown number of civilians and livestock present in the area as well as the time it would take before the entire region would be flooded. The first exercise was for field units primarily focusing on operational echelon response activities. The next exercise was the tactical echelon, which picked up where the field units (operational echelon) left off.

Finally, the strategic echelon exercise picked up where the tactical echelon left off. Hence, the trainers used the information output of each exercise as input for the next higher echelon in the exercise. In this way, each exercise was dependent on the information provided by the preceding one. During each exercise, the trainers also provided counter play to the echelon in training. For example, during the training of the tactical echelon, the counter play communicated decisions of the strategic echelon and information needs of the operational echelon. The exercise participants were not familiar with the exercise plot. They took the exercise seriously and were committed to achieve the exercise goals even though they knew a real disaster situation might develop in a completely different way.

We collected data by observing how relief workers use information systems and how relief agencies share information for decision-making. The second instrument is document analysis (prior to and after the exercises). Using reports on the exercise setting, objectives, IT applications, and participating agencies we were able to generate a field study protocol prior to the observations (see Appendix-B). In addition, we used some of these documents to triangulate the findings from the observations. The third research instrument is a survey that we administered during an exercise of the tactical echelon.

Generally, the disaster response exercises are not evaluated immediately after the exercise, apart from a collective briefing (not more than 5-10 minutes) in which the chiefs of the participating agencies reflect on the exercise. In our view, this evaluation approach is necessary but does not result in a more detailed understanding of the hurdles for IQ and SQ. Moreover, the briefing process is generally quite diverging in nature and the majority of participants do not get an opportunity to reflect on the exercise. Hence, we proposed to hand out a short one-page survey, specifically on IQ and SQ issues.

### 4.4.1 Actors and coordination structure

This section focuses on actors and coordination structure the operational level of disaster management. Hence, this chapter continues with a detailed elaboration of the tactical echelon exercise. Since we were not able to collect data from the German side of the exercise, we focus on the Dutch coordination structure. The following schema represents the coordination during the operational level exercise.

**Figure 4-9: Coordination structure in the Gelderland field studies**
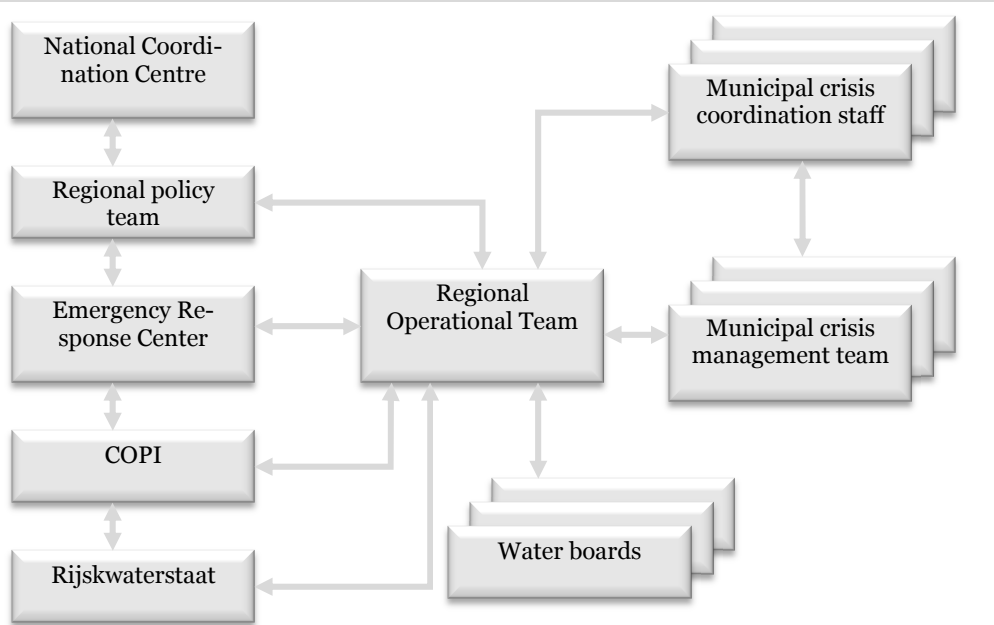
The coordination structure during the VIKING exercise emphasizes the role of the Water boards and Rijkswaterstraat in the disaster response process. This is due to the high risk of major flooding in the Gelderland region. In addition, the municipal crisis coordination staff and the municipal crisis management teams also play an important role. In this field study, we focus on the Regional Operational Team (ROT). The following table outlines the type and number of relief agencies observed in the tactical level exercise.

**Table 4-10: List of agencies participating in the disaster response exercise**

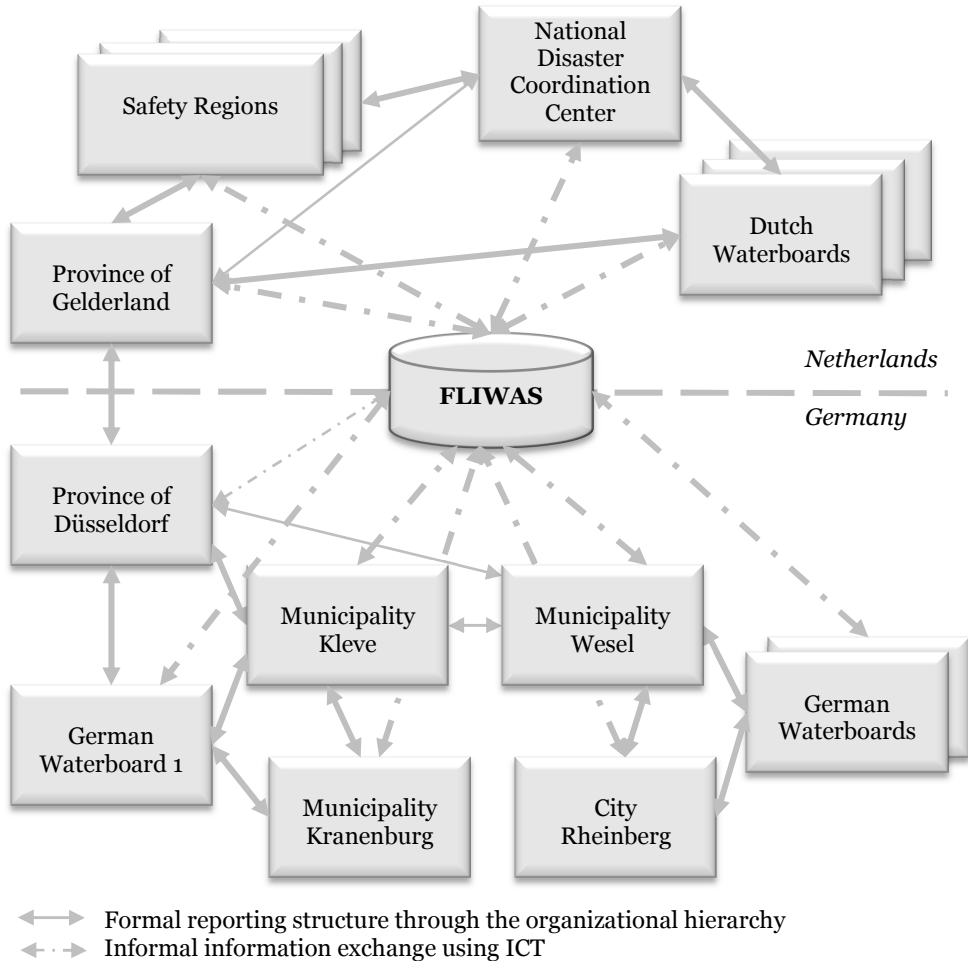| Disaster management agency | Participants # |
|---|---|
| Fire department | 9 |
| Police department (plotters) | 4 |
| Police department | 6 |
| Municipality services | 4 |
| Fire department | 5 |
| Ambulance services | 5 |
| Regional flood control board | 6 |
| Public Relations, Press | 5 |
| National army | 1 |
| National water management institute (Rijkswaterstaat) | 3 |
| Exercise organization | 3 |
| Total | 51 |

Table 4-10 outlines the main agencies involved in the ROT during the tactical echelon training exercise. This team is comparable to the ROT discussed in the Rotterdam-Rijnmond coordination structure. We discuss the applications used in the ROT in the next sections.

### 4.4.2 Information management practices

According to the project proposal, the initial goal of Program VIKING was to enhance cross-border collaboration and information sharing. One of the deliverables expected from the program was an information architecture that could support cross-border information flows during floods. Initially, the alliance of agencies did not intend to develop a new IT application. The steering committee examined the existing IT-applications in both countries, in an effort to find the best way to integrate the IT- applications already in place. However, the analysis reports revealed that the existing IT-applications not only lacked functionality for information management (e.g., generating situation reports), but also included overlapping functionalities (e.g. view area maps). After studying these analysis reports, the steering committee concluded that it would be more viable for the partners to develop an entirely new IS for cross-border DM. This conclusion led to the development of FLIWAS. The purpose of FLIWAS was, according to an internal record, to "enable water management officials to make decisions based on real-time data in disaster situations, assuring that all decision-makers have access to the same information and reduce the uncertainty on both sides of the border." The FLIWAS design guidelines specify that: the application (1) must be multilingual (Dutch, German and English), (2) web-based (invocation via a browser), (3) come in multiple versions with a modular-architecture, and (4) comply with open standards. Major functional modules developed to date include flood visualization, flood level and risks prediction, evacuation scenario simulation, and emailing. Figure 4-10 illustrates the FLIWAS-based information flows between different Dutch and German relief agencies.

As illustrated in the Figure 4-10, only one formal communication channel existed between province of Gelderland and Region of Düsseldorf at the policy-making level, which had to mediate all cross-border information flows from/to the water boards and regional DMOs in their jurisdictions. Even within a country, not every DMO had a direct formal connection with every other DMO. FLIWAS enabled DMOs to bypass the formal reporting channels and instantly exchange information with each other to create a shared situational picture of the status of dikes, water level, and pumps during a flood.

Similar to the generic information objects shared during the Rotterdam field studies (Table 4-5), we have observed that relief workers shared several types of information across agencies and echelons. What we noticed was the major focus on collecting and sharing object information. Here the main object of interest among all the relief workers was the flood. Relief workers were particularly interested in information on the flood levels and affected area.

**Figure 4-10: Cross-border information flows during VIKING exercise**



Formal reporting structure through the organizational hierarchy

Informal information exchange using ICT

In the Gelderland case, the role of 'plotter' was more explicit than of an information manager. Water board officials played the role of plotter during the exercise. The plotter is usually outside the decision-making unit and functions as low control (close to the incident). Agencies used two different versions of plotting software, one of which is web-based while the other was a thick client running on each of the individual computers. This often resulted in different plots of the flood area. Plotters are expected to aggregate information into maps, pictures and figures of the situation and share this with the information managers in the decision-making units. The capabilities the plotter had available were similar for both cases and comprised of data visualization and map generating applications. In addition, the plotter had the capability to enrich the plots by adding information on the wind speed and potential hazard area. The latter capability proved very valuable for a

number of the exercises in Gelderland, were the commanders of the relief agencies needed to develop a common operation picture on the area that would be flooded.

In Gelderland, the decision-making unit on the strategic level did have two beamers that could project plots and situation reports on the wall. This capability allowed the chair to structure the information sharing process according to the plots and situational information and synchronize the situational awareness of the agency commanders. In the back-office, we did observe some problems with synchronizing the situation reports on the central beamers in the room. The reason for this is that the same information manager who was responsible for situation report generation in the front office (during the decision-making rounds) was responsible for updating the situation report on the shared screen in the back office. Because of time pressure and task-overload, this information did not change the situation report in the back office. After a while, the agents in the back office did not look at the screens, as they knew the information it displayed was outdated. This lack of capability hampered the creation of shared awareness in the back office.

### 4.4.3   Multi-agency information management applications

In contrast to the Rotterdam-Rijnmond field studies, the Gelderland training exercises included three different applications for multi-agency information sharing. All of the participants of this exercise made use of one of the four applications for multi-agency information sharing, which was not the case in the other exercises. The following table provides a brief description of these IT-applications.

**Table 4-11: Overview of IT applications used for multi-agency information management**

| Application | Purpose and functionalities |
| --- | --- |
| CCS | Relief workers could use CCS for messaging and situation report communication. This application is a customized version of Microsoft Groove. We observed that some relief workers also refer to this application as "sittext", which is short for text on the situation. Only the information manager can edit and share information using CCS. |
| ARCmap | In order to visualize geographic information, ARCmap is used. The main result of this application is also referred to as sitplot. There are multiple versions of this application used. The latest version (1.0) used in Gelderland Zuid is web-based and the previous version used in Gelderland Midden (0.9) is stand-alone (running on the client machine). |
| FloodAtlas | This stand-alone application allowed agencies to simulate flooding and waterlevels and project this information on various maps of the region. |
| FLIWAS | Flood Information and Warning System (FLIWAS) is a high water information application build from Dutch German cooperation and is funded by the EU. The purpose of this application is to optimize the exchange of information during (threatening) high water situations within and between water management and calamity management organizations. This application is build using generic components (e.g. communication with databases, internal and external communication, import provider, plan module and web mapping). Relief agencies employed multiple versions during the exercises, including FLIWAS-Light and FLIWAS comfort. |

It is no exception that emergency responders interact with multiple ITs, directly or indirectly through an intermediary (e.g., dedicated operator). Such ITs are often developed by different disaster management application development initiatives, and some of the ITs may be integrated, redeveloped, and/or repackaged later by another initiative, making it very difficult to draw a clear boundary of IS in a DM situation. However, from an insider's perspective any IT supported in a disaster management situation was perceived as a part of a disaster management information system. For this particular PSN, a disaster management information system is an ad hoc combination of IT applications providing functionalities such as flood simulators, messaging, document sharing applications, geographical maps, etc. In order to provide a common reference frame, we listed the names of the four main IT applications supported in the exercise (FLIWAS, ARCmap, CCS and Floodatlas) at the beginning of the questionnaire. We asked respondents to indicate each of the IT-applications they used and/or name the application if it was not one of the major applications listed.

**Figure 4-11: Screenshot of the FLIWAS application (light version)**
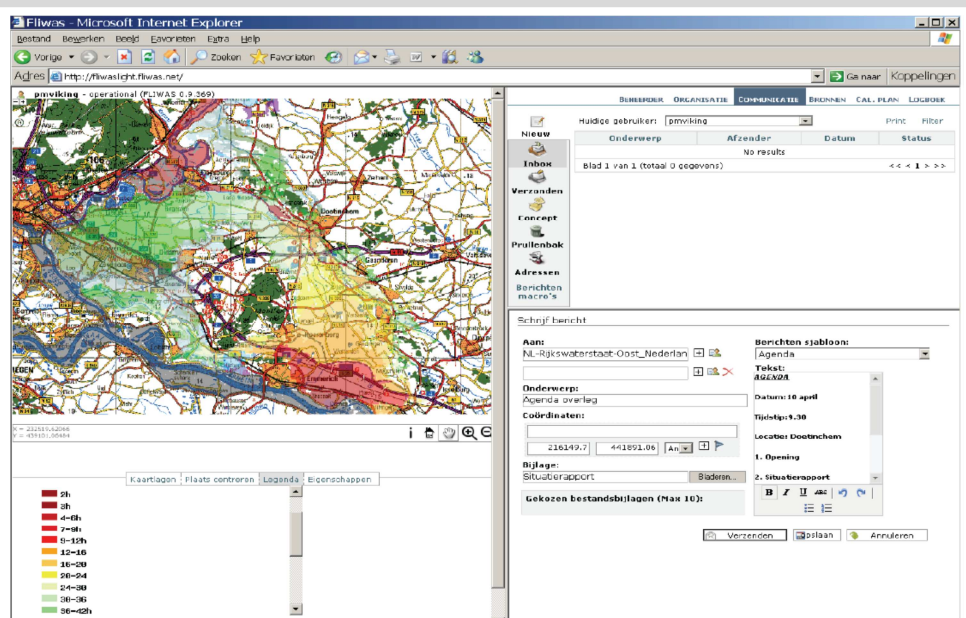


The screenshot above illustrates some of the functionalities of the FLIWAS application for cross-border information sharing. Functionalities include flood monitoring, situation report generation, and sharing attachments (e.g., documents, photos etc.). Similar to CEDRIC, the mailbox section of FLIWAS follows a Microsoft Outlook design. Note that the depicted FLIWAS version is the web-based 'light' version of this application. The original version needs to be pre-installed on the user desktop or laptop.

### 4.4.4   Qualitative data: observed IQ and SQ issues

Regarding the motivation to use one of the four IT-applications, the effects of task support and the group value were evident in interview responses, although the strong mediating effect of the attitude concept (i.e., user satisfaction) was not obvious. For example, we observed that some exercise participants who were expected to share information using FLIWAS did not do so. When asked why, they often responded, "I have a lot of other stuff to worry about and do not see the direct advantage of using FLIWAS for my own tasks." On the other hand, some frequent users of FLIWAS indicated that they used this application because "the system might contain valuable information for our [the participant'] organization and our colleagues on the other side of the border might need the information we have."

The interviews with the exercise leaders and information system architects were very helpful in understanding the design principles and roles of information technologies in cross-border disaster response. As mentioned earlier, Program VI-KING aimed to improve emergency responses to large-scale floods that often span across the Dutch-German border. Consequently, most ROAR exercise participants shared the idea that helping others in the larger community of same faith is helping themselves. An IS architect emphasized this as "Cross-border crisis management requires collaboration of several relief agencies from both countries. … It has been two years since we have developed an IT application (i.e., FLIWAS) that can support relief agencies collaborating on both sides of the borders." Nevertheless, need for and capability of an IT application do not guarantee acceptance, especially in a time crunching, life-threatening situation. As this architect noted "Each of these [participating] relief agencies has its own preference for using a specific IT application [for its own responsibilities], and it is difficult to enforce a single standardized application." An exercise leader also added, "Despite the expected value of FLIWAS for the participating agencies, we still need to gain the support of policy makers and individual emergency responders in utilizing FLIWAS for cross-border information sharing. These cross-border exercises are meant to demonstrate the value to the disaster management community [around the flood-prone region]."

Some other interviewees also pointed out that it was far more difficult to encourage the tactical and operation level emergency responders to use FLIWAS because they usually have limited scope and understanding of the situation. One respondents complained, "They [tactical & operational level emergency responders] only focus on intra-organization information sharing instead of inter-organizational or cross-border," even though their commanders on both sides acknowledged the value of using FLIWAS.

As observers we found that the most visible IQ issue was the inconsistency of information shared using the various applications (i.e., FLIWAS, CCS, ARCmap). Since relief agencies were allowed to use their own IT applications for intra-agency information management while also using of FLIWAS, CCS or ARCmap for inter-agency information sharing, multi-channel management was a major challenge. Often, the inconsistencies of information in the various systems was only apparent during the ROT team meetings, after which each commander returned to the stations with either request for medications (in the existing dataset) or clarifications (e.g., where exactly is the ship located?).

Another IQ issue we observed was the outdated information on the central screen in the ROT. The person responsible for depicting the most recent (updated) situation report on this screen was busy with other tasks. While several relief work-

ers did consult the situation report at the start of the training exercise, the number of views gradually reduced after relief workers started to understand that the information was outdated. Regarding the SQ, the most pressing issue we observed was the accessibility of information about the hazardous cargo of the ship. Since it was an international ship, it was difficult for the relief agency commanders to get access to the cargo registration list of this ship. Consequently, some decisions regarding the evacuation of residents near the river (in case of toxic gases) were recurrently delayed due to the lack of information. Finally, we observed some minor start-up issues for FLIWAS and ARCmap.

### 4.4.5 Quantitative data: survey findings

Immediately after the exercise, we requested the still present relief workers to fill in a survey. We obtained a 90% response, as almost 47 of the 51 relief workers participated in the survey. The following pie chart shows the DM agencies and the number of emergency responders from each of the agencies participated in the surveyed (tactical echelon) exercise.

**Figure 4-12: Sample description for the Gelderland surveys**
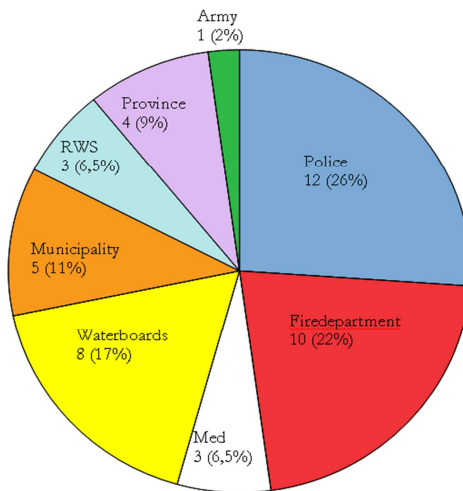


The majority of participants in the ROT exercise were from the regional police department. The second largest group of participants represented the regional fire department. One representative of the national army was also present. In total 46 out of the 51 participants responded to our short paper survey. This high response rate (90%) was because the exercise organizers encouraged the participants to fill in the surveys on our request. Similar to the survey administrated in the Rotterdam-Rijnmond field studies, we formulated questions as propositions regarding the IQ and SQ experienced during the exercise. In contrast to the Rotterdam-Rijnmond surveys, the surveys we used here only included one item per construct (as opposed to three). The main reason for this is that the exercise organizers in-

sisted the surveys would not be longer than a single page, since relief workers were on duty and needed to return to their tasks as soon as possible. Since the surveys were very short, we had no problems regarding missing data values and incomplete surveys, which was the case in the Rotterdam-Rijnmond web-surveys. We discuss the scores for the IQ and SQ in the next figures.

**Figure 4-13: Information Quality Scores for the Gelderland surveys (n=46)**
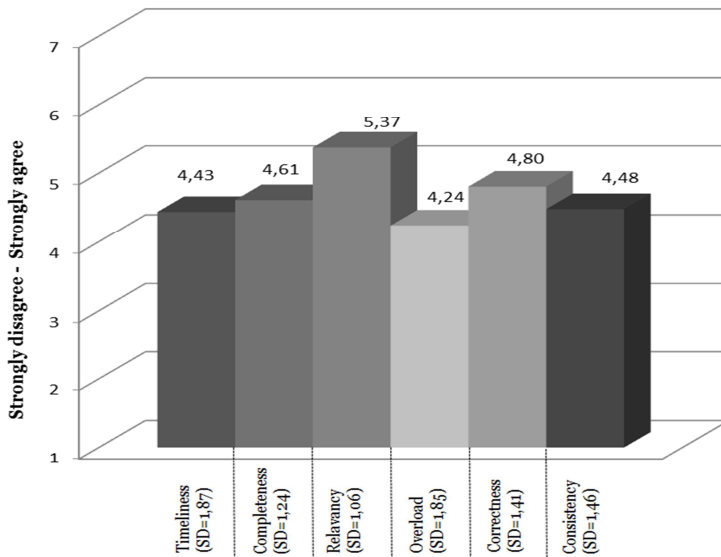


The scores regarding the IQ dimensions can be considered moderate, with the exception of the relevancy dimensions, which with an average score of 5,36 can be considered as medium-high. As such, we could conclude that the use of the different applications (i.e., FLIWAS, CCS, ARCmap) did not create problems regarding the relevancy of the information. Noteworthy is the average score for the perceived information overload (average=4,24), indicating no real issues regarding the amount of information. The standard deviation for the information overload dimension is however relatively high (SD=1,86), indicating that there were some participants who did score high regarding information overload.

Figure 4-14 provides the average scores and standard deviations for the SQ variables. This survey also asked the respondents to first indicate which application (i.e., FLIWAS, CCS or ARCmap) they have used during the exercise. The average scores for the SQ dimensions are also in the same range, with the exception of the information system flexibility. However, compared to the standard deviation scores for the IQ, the standard deviation scores for the SQ dimensions are higher.
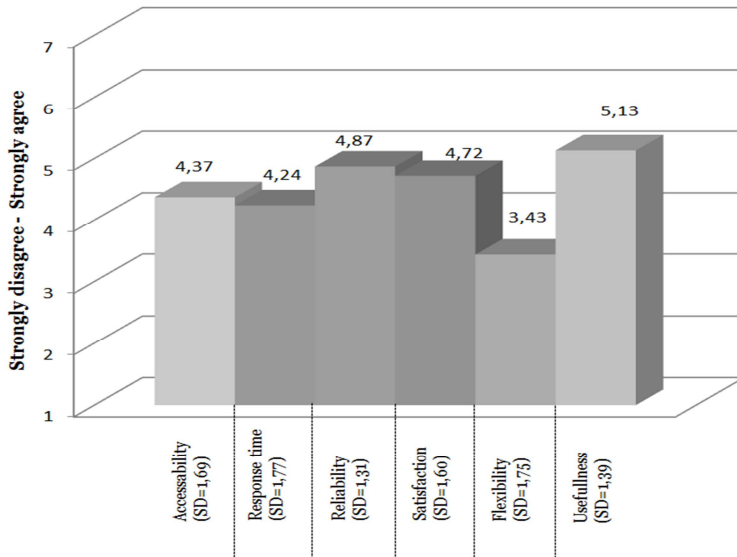
**Figure 4-14: System Quality Scores for the Gelderland surveys (n=46)**



Figure 4-14 allows us to conclude that the participants were satisfied with the applications they have used (average: 4,72) and found the respective applications very useful in supporting their tasks (average=5,13). The average score for the information system flexibility is relatively low (average=3,43), indicating that the application used could not sufficiently provide information which was not anticipated beforehand. In addition, the standard deviation for this dimensions is relatively high (SD=1,75), indicating some spread in the scores of the participants. Since we only used one item per construct in the survey for this field study, we were unable to conduct a reliability analysis.

## 4.5    Field study #3: Delfland

Our third and final field study entails the management of information within a single agency during a disaster. We observed a full day exercise at the Hoogheemraadschap Delfland (HHD), which is the water management board in the The Hague region. The exercise we observed took place on March, 25th, 2010 in Delft and was titled "Waterbreuk", indicating the effects of a flood in the densely populated Delft area. This exercise involved 40 participants, the majority of which were on duty during the exercise. The main goals of this exercise were to train the response procedures of the HDD and information management within the agency. Particularly, this exercise caught our attention since the HHD does not employ electronic information systems for disaster response. Instead, the HHD employs traditional means such as whiteboards and paper based situation reports for intra-agency information sharing. Similar to the previous two field studies, we had built up a mutually beneficial relationship with the exercise leaders, enabling us to col-

lect data in exchange for our findings. We discuss the actors and coordination structure during this exercise next.

### 4.5.1 Actors and coordination structure

The exercise included 41 players (31 participants and 10 counter players). In the counter playing teams, individuals push information to the actual participants by representing the outside environment. The majority of participants were active in the supporting sections of the HHD. The supporting sections represented specific departments, each responsible for a different aspect of water management, including water filtering and infrastructure maintenance. Noteworthy was that as a water management agency, the HHD followed a somewhat different disaster coordination structure than the GRIP structure discussed in section 4.1.

The coordination of actors during this exercise was similar to the ones in the previously mentioned exercises. Again, trainers simulated three echelons of decision-making: the strategic, tactical, and operation echelon. Figure 4-17 illustrates these echelons.



**Figure 4-15: Actors and coordination structure in HHD exercise**
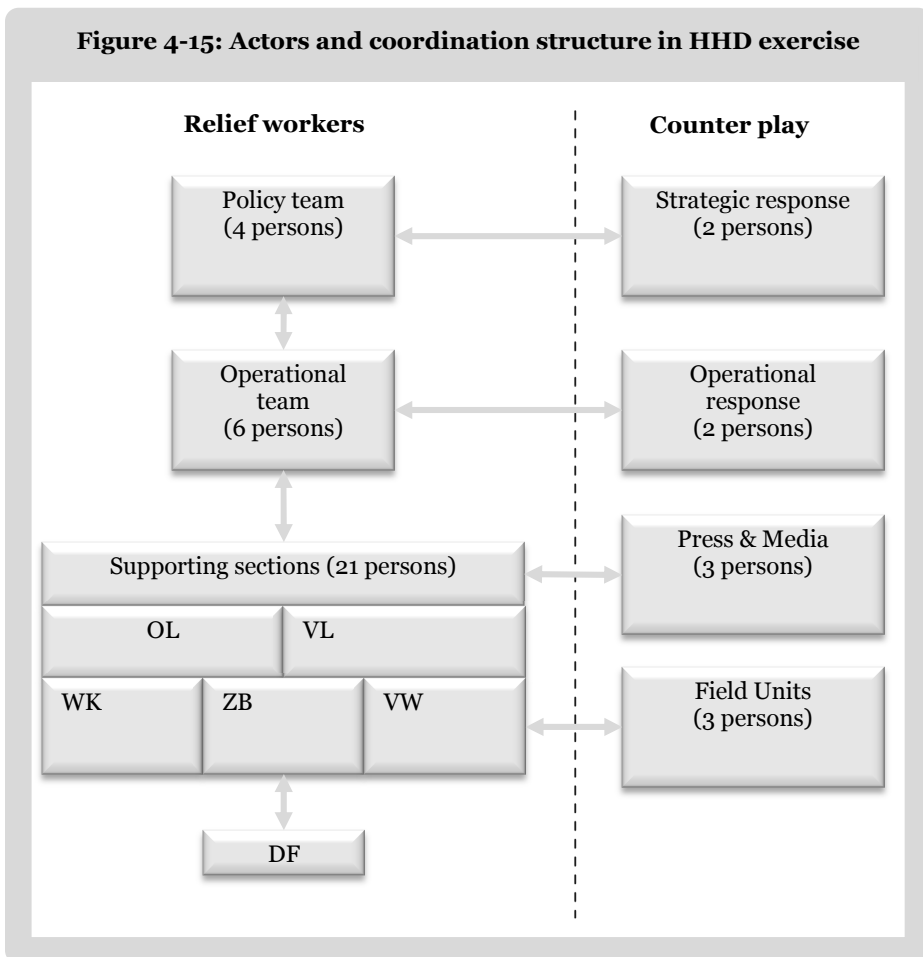
During disasters, the response structure of the HHD is dictated by three coordination levels: 1, 2, and 3. Basically, these numbers represent the echelon that needs to be activated in order to combat the effects of an incident. In level 1, the supporting sections lead the response, in level 2 the operational team leads the response and in level 3 the policy team leads the response. Nevertheless, the trainers also explained the GRIP levels in a presentation prior to the exercise. It seems that both coordination structures exist and are used, 3 levels for intra-agency coordination and GRIP for interagency coordination.

### 4.5.2   Information management practices

The information flows during the exercise were in accordance with the coordination structure depicted in figure 4-18. The decision-making teams sat in three separate rooms in the same building. The majority of participants active in the supporting sections sat in the main room. The following figure outlines the information flows in the HHD exercise.



**Figure 4-16: Information flows in HHD exercise**
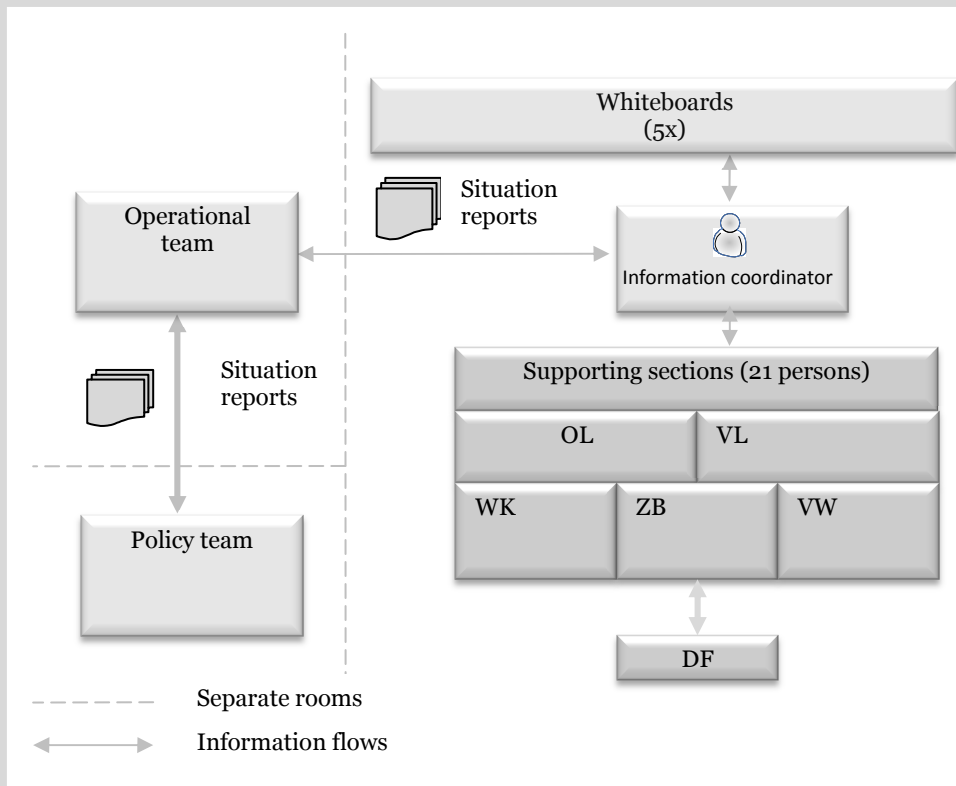
The HHD also uses situation reports (similar to Rotterdam-Rijnmond) to share information between the echelons. In addition, the policy team and the operational team regularly met during the exercise in order to share information and make decisions on combating the flood. Each team included someone who used a

laptop for developing a situation report. The assistance in each echelon generated situation reports on a laptop and emailed these to the assistants in the other echelon. Since most of the members did not have the means to check their email during the exercise, assistants often printed situation reports on paper and handed these to the other members of their team. The main room contained five large whiteboards for inter-departmental information management. The following picture (Figure 4-17) gives an impression of the whiteboards used during the exercise. The structure of the whiteboards contained a comprehensive categorization of information and action, more than what we have observed in the Rotterdam and Gelderland field studies. Similar to the generic information objects shared during the Rotterdam field studies (Table 4-5), we have observed that these whiteboards included several types of information across departments. While we again noticed the focus on collecting and sharing object information (object here is flood), the whiteboards also contained much risk-objects and planning information.

**Figure 4-17: Whiteboards for information management**



In total, exercise trainers employed five whiteboards for information management. The trainers had numbered the whiteboards and predefined categories for information posting. Even though the whiteboards functioned as inter-departmental information system, they provided no (active) functionality beyond the presentation of information posted by the operator. Only one specific role, the 'information coordinator' (IC) was allowed to manage information using the whiteboards. This means that IC was the only relief worker allowed to add or remove information from the whiteboards. Naturally, the handwriting of the IC was not clear to everyone. The IC had several colored whiteboard markers to his disposal

and started the exercise with the intention to use a different color marker each time he would write new information in the same category. The idea here is that the use of different colors would highlight new from old information.

### 4.5.3   Qualitative data: observed IQ and SQ issues

During the HHD field study, we also observed several IQ and SQ issues. First, there was the repeating issue of understandability regarding the text posted on the whiteboards (see figure 4-19). This issue refers to the format of information, as an IQ dimension. Sometimes two or three relief workers actually stared at the whiteboards for several minutes trying to figure out what the IC had written. A second issue we noticed was the inconsistency between the situation reports distributed between the teams. While some of the supporting sections did have some kind of template for typing situation reports (in Microsoft Word), other sections started from scratch. As a resulted, we observed that the situation reports shared contained different fields of information.

Another issue we observed was the role of the IC. The IC had an assistant, called the 'assistant information coordinator'. This role is supposed to aid the IC in his tasks. However, throughout the exercise we did not observe much interaction between the IC and his assistant. Moreover, we observed that the IC was often in discussion with the leaders of the different supporting sections. As a result, we observed a steady reduction in the addition of information on the whiteboards. This also led to some problems regarding the timeliness of the information on the whiteboards: is the information posted an hour ago still up-to-date? Similar to the field studies in Rotterdam, we were also able to survey relief workers to state what kind of IQ and SQ issues they experienced during the exercise. The following table outlines some of these IQ and SQ issues. We translated these statements from Dutch to English without any modifications to their original meaning.

**Table 4-12: IQ and SQ issues experienced by the relief workers**

| Statements provided by the relief workers | IQ dimension | SQ dimension |
|---|---|---|
| "it was not clear to me to whom to send the information that I possessed" | Relevancy | Interoperability |
| "it was not clear who the right contact points in the supporting sections were" | - | Accessibility |
| "we need to verify and validate our situation reports in order to be clear on what has been decided and what is pending" | Correctness | - |
| "it was unclear when an what new information was posted on the whiteboards" | Timeliness | - |
| "the whiteboards were not user friendly. The text was too small difficult to understand" | Format | User-friendliness |
| "we need better geographic information tools and facilities" | Format | Interoperability |
| "our section leader was too caught up in all kinds of meetings. As a result, our team lacked information" | - | Response time |
| "there was some confusion about the GRIP level (1 or 3) and the delayed reaction from the operational and policy team made the situation even worse" | Consistency | Interoperability |
| "we did not share sufficient information within our team" | Amount | - |
| "some frequently asked questions demanded more time for answering them" | - | Response time |
| "some questions were hanging for too long and were ever answered" | - | Response time |
| "there was some confusion regarding the communication stop to the press and our organization's strategy on dealing with this" | Consistency | Interoperability |
| "the information coming from the operational team and policy team should have reached us faster" | Timeliness | Response time |
| "it was unclear on the whiteboards what the messages were, what the questions were and what the instructions were" | Format | User-friendliness |
| "we experienced some difficulties in dealing with new information coming from the operational team and policy team" | Timeliness | Response time |
| "we had to wait to long for some input and output regarding the Q&A section of our website" | Timeliness | Response time |
| "i had to share information much quicker, including the provision of some answers to the questions of some of my colleagues" | Timeliness | Response time |
| "the information coordinator went beyond his role....he started giving instructions and asked some questions" | Completeness | - |
| "the situation reports did not include the most recent information because the situation reports were send too late" | Timeliness | Response time |
| "much information was too difficult to access, for instance about the dikes" | Completeness | Accessibility |

The table above lists some of the IQ and SQ issues experienced by the relief workers themselves. Some of these are more about the whiteboards and infor-

mation coordinator (IC) compared to others. We also see some issues regarding the unclear text on the whiteboards and the situation reports we mentioned earlier. The next section presents the overall scores for the IQ and SQ as experienced by the relief workers.

## 4.5.4 Quantitative data: survey findings

Similar to the Gelderland field study, exercise trainers allowed us to distribute paper-based surveys immediately after the exercise. The actual participants of the exercise and not the counter playing roles completed the surveys. This reduces our sample to 31 participants. We received 24 completed surveys, leveraging a response rate of 77%. Since the exercise organizers did not specifically request us to reduce our survey to a certain page length, we were again able to use three items for some of the constructs. We discuss the preparation and reliability of these items in the next subsection.

### 4.5.4.1 Data preparation and reliability analysis

The data collected from the paper surveys were prepared and analyzed in SPSS 17.0. Since we used multiple items to measure a single construct, we were able to conduct a reliability analysis prior to calculating the average scores and standard deviations (discussed in the next section). The following table outlines the findings of the reliability analysis.

<div align="center">

**Table 4-13: Reliability analysis for HHD survey items**

</div>

| Dimension | IQ/SQ Items | Cronbach's α |
|---|---|---|
| IQ_TIMELINESS | C_IQ_TIMELINESS_A <br> C_IQ_TIMELINESS_B_REC <br> C_IQ_TIMELINESS_C_REC | .788 |
| IQ_CORRECTNESS | C_IQ_TIMELINESS_A <br> C_IQ_CORRECTNESS_B_REC <br> C_IQ_CORRECTNESS_C_REC | .789 |
| IQ_COMPLETENESS | C_IQ_COMPLETENESS_A <br> C_IQ_COMPLETENESS_B_REC <br> C_IQ_COMPLETENESS_C_REC | .803 |
| IQ_OVERLOAD | C_IQ_OVERLOAD_A <br> C_IQ_OVERLOAD_B_REC <br> C_IQ_OVERLOAD_C *(discarded)* | .471 |
| IQ_RELEVANCY | C_IQ_RELEVANCY_A <br> C_IQ_RELEVANCY_B_REC <br> C_IQ_RELEVANCY_C_REC | .736 |
| IQ_CONSISTENCY | C_IQ_CONSISTENCY_A <br> C_IQ_CONSISTENCY_B_REC <br> C_IQ_CONSISTENCY_C_REC | .845 |
| SQ_RESPONSETIME | D_SQ_RESPONSETIME_A <br> D_SQ_RESPONSETIME_B <br> D_SQ_RESPONSETIME_C_REC | .556 |
| SQ_ACCESSIBILITY | D_SQ_ACCESSIBILITY_A <br> D_SQ_ACCESSIBILITY_B *(discarded)* <br> D_SQ_ACCESSIBILITY_C | .754 |
| SQ_SATISFACTION | D_SQ_SATISFACTION_1 <br> D_SQ_SATISFACTION_2 | .868 |

The table presents the values for the Cronbach's Alpha which is a measure for the internal reliability of a scale used for each construct. Note that the constructs that were only measured through one item (i.e., SQ ease of use and SQ digitalization) are not listed in the table. As discussed in section 4.3.6.1, the following norms for interpreting the Cronbach's Alpha coefficient: > 0.9 is considered: excellent; > 0.8: good; > 0.7: Acceptable; > 0.6: questionable; > 0.5: meager, and < 0.5: unacceptable. Note that these norms assume a large data set (over 100 cases), whereas our data set contains 24 cases. Considering the norms, the Cronbach's Alpha for SQ_OVERLOAD (.471) is definitely unacceptable even when deleting SQ_OVERLOAD_C, pointing towards a low internal reliability for this construct. The second Cronbach's Alpha that raises some concerns about the items we used is the Cronbach's Alpha for the SQ_RESPONSETIME (.556), which we interpret as meager. The remaining constructs have an 'acceptable' or even 'good' Cronbach's Alpha (in some cases after one of the item scales is discarded). The following section discusses the IQ and SQ averages, after we discarded the items that reduced the scale reliability.

### 4.5.4.2 Average IQ and SQ scores

Similar to the relief workers in Rotterdam and Gelderland, we requested the relief workers in Delft to reflect on the IQ and SQ dimensions after the training exercise. For this purpose, we employed paper-based surveys that we administered immediately after the exercise. The following figures outline the averages scores for the perceived IQ and SQ during the exercise.



**Figure 4-18: Information Quality Scores for the Delfland surveys**
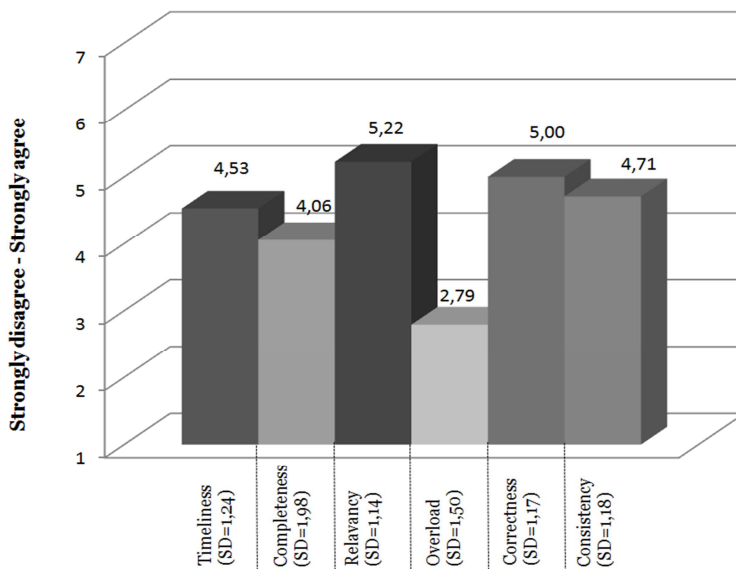
Noteworthy is the relatively low score for information overload (average=2,79), indicating that the relief workers experienced low information overload during the exercise. We can explain this by considering the use of whiteboards during the exercise. The whiteboards are well categorized and do not send/distribute information actively (as opposed to CEDRIC or FLIWAS). As a result, relief workers forage information on their own behalf. While the average score for the completeness of information (average=4,06) can be classified as moderate, the average score for the relevancy of information (average 5,22) indicates that the information shared, albeit incomplete, was often correct. The standard deviation for completeness (SD=1,98) does however indicate some spread in the scores of the relief workers. Also noteworthy is that the relevance of information to be relatively high in the analysis emerges. This means that most respondents found that the information shared with them was relevant for performing their tasks. Apart from propositions on the IQ, we also requested respondents to state their agreement on some propositions regarding the information system quality in our survey. Prior to these propositions, we explicitly referred to the whiteboards and information coordinator as components of the information system in question. The following figure outlines the average scores for the SQ.



**Figure 4-19: System Quality Scores for the Delfland surveys**
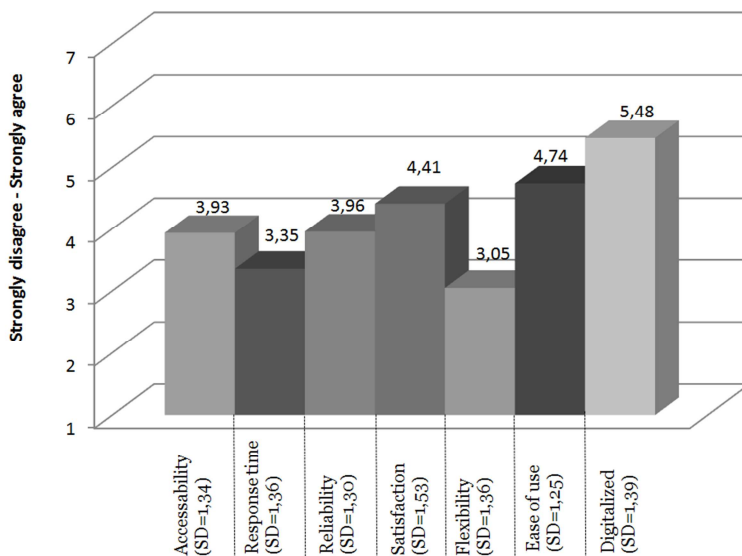
The first thing noticeable in figure 4-19 is the relatively low scores for flexibility (average=3,09) and response time (average=3,35). The low average score for flexibility can be attributed to the fixed set of functionalities provided by the whiteboards. The whiteboards for instance do not support the exchange of multimedia information formats such as images and videos. The low average score for response

rate indicates that the participants experienced some delay between their request for information and the time that that information became available. The dependence on the IC for information can be an explanation for the low response time. Notice the low average score of the reliability (average= 3,96) of the information system. This indicates that the participant could not always count on the combination of information coordinator and whiteboards for information. Nevertheless, the participants were relatively satisfied (average=4,41). This can be partly explained by considering the score for the ease of use (average=4,74). This could mean that the participants found the use of whiteboards (moderated by the information coordinator) as relatively easy way to share information. Yet, the majority of respondents agreed with the proposition that the information on the whiteboards should be presented in a digital manner. We asked this question on the digitalization of the whiteboards because there is a discussion within the HDD on employing a digital (online) application for information sharing.

## 4.6   Cross-field study findings and conclusions

The chapter reports our main findings from conducting three field studies in the Netherlands. The field studies provide valuable insights on the information management architectures currently used in public safety networks. These insights are a prerequisite for designing information systems that ensure IQ and SQ for relief workers, something we continue with in chapter 6. We did not set out to compare the findings from the three field studies because we were aware of the differences in relief workers, their level of training, the available resources and the scenarios trained. In addition, even though we employed the same set of data collection instruments for the three field studies, the data collection opportunities (e.g., sample sizes, paper vs. electronic surveys) were different. However, while aware of these differences, to some extend comparison between field studies is possible since the field studies were complementary in terms of information system architectures (e.g., applications, roles, and information flows). In the remainder of this chapter, we discuss cross-field study findings in the form of general observations induced from the field studies. First, we discuss some results from an ANOVA test in the final section of this chapter that compares the means between the three field studies.

### 4.6.1   Analysis of variance between field studies

While the main goal of the field studies was to explore information systems and information management capabilities in practice, the quantitative data we collected also provides the opportunity for 'comparison'. Here, comparison refers to the analysis of variance (ANOVA) between the data collected from the three field studies. While the field studies are not equal in respondents, coordination structures and information management practices, we can compare the IQ and SQ scores collected from the three field studies. ANOVA tells us whether three or more means are the same, so it tests the hypothesis that all group means are equal (null-hypothesis). The following table outlines the findings from the ANOVA test in SPSS 17.0.

**Table 4-14: ANOVA results**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| IQ_Timeliness: the information was up to date | Between Groups | ,984 | 2 | ,492 | ,318 | ,728 |
| | Within Groups | 232,376 | 150 | 1,549 | | |
| | Total | 233,359 | 152 | | | |
| IQ_Correctness: the information was with-out error | Between Groups | ,690 | 2 | ,345 | ,220 | ,803 |
| | Within Groups | 232,217 | 148 | 1,569 | | |
| | Total | 232,908 | 150 | | | |
| IQ_Completeness: the information was com-plete | Between Groups | 11,406 | 2 | 5,703 | 3,967 | ,021 |
| | Within Groups | 215,632 | 150 | 1,438 | | |
| | Total | 227,038 | 152 | | | |
| IQ_Consistency: the information system provided consistent info | Between Groups | 6,043 | 2 | 3,021 | 1,435 | ,241 |
| | Within Groups | 313,779 | 149 | 2,106 | | |
| | Total | 319,822 | 151 | | | |
| IQ_Relevancy: the in-formation provided was relevant | Between Groups | 1,607 | 2 | ,804 | ,746 | ,476 |
| | Within Groups | 161,540 | 150 | 1,077 | | |
| | Total | 163,147 | 152 | | | |
| IQ_Reliability: The information provided was reliable | Between Groups | 25,178 | 2 | 12,589 | 16,610 | ,000 |
| | Within Groups | 112,932 | 149 | ,758 | | |
| | Total | 138,110 | 151 | | | |
| SQ_Accessibility: The IS was accessible | Between Groups | 33,243 | 2 | 16,622 | 8,600 | ,000 |
| | Within Groups | 287,974 | 149 | 1,933 | | |
| | Total | 321,218 | 151 | | | |
| IQ_Overload: Use of the IS leads to infor-mation overload | Between Groups | 46,481 | 2 | 23,240 | 9,992 | ,000 |
| | Within Groups | 346,572 | 149 | 2,326 | | |
| | Total | 393,053 | 151 | | | |
| SQ_ResponseIime: the IS provided me rapidly in my information needs | Between Groups | 18,599 | 2 | 9,299 | 3,024 | ,052 |
| | Within Groups | 461,284 | 150 | 3,075 | | |
| | Total | 479,882 | 152 | | | |
| SQ_Satisfaction: I am satisfied with the IS | Between Groups | 24,914 | 2 | 12,457 | 4,290 | ,015 |
| | Within Groups | 429,722 | 148 | 2,904 | | |
| | Total | 454,636 | 150 | | | |

Table 4-13 outlines the results of the ANOVA between three groups. Here, groups refer to the relief workers in Rotterdam-Rijnmond, Gelderland and Delfland. ANOVA has the advantage that it can be used to analyze situations in which there are several independent variables (Field, 2005; p.309). Independent variables include the IS application used, the type of information management roles, and the coordination structure. Since we did not have control over the exper-imental conditions in each of the exercises, we cannot determine the effect of the

individual independent variables on the dependent variables (i.e., IQ and SQ dimensions). For this purpose, our observations were critical. We can however consider the set of independent variables as a specific 'information management architecture' and reflect on the effects of the information management architecture on the dependent variables across the three groups using the ANOVA results.

For each dimension, the rows in the table are divided in between-group effects and within-group effects. Important indicators for this table are the F-ration and the Significance value. The F-ratio compares the amount of systematic variance in the data to the amount of unsystematic variance. However, this ratio does not tell us where the differences between groups lie. Considering significance at the 0.05 level, the significance value for the dimensions IQ_Timeliness, IQ_Correctness, IQ_Consistency and IQ_Relevancy allow us to conclude that for these dimensions the group means are not significantly different. For the remaining dimensions, the means are significantly different across the groups.

The assumptions under which ANOVA is reliable is the same as for all parametric tests based on the normal distribution (Field, 2005; p. 324). These assumptions are: (1) data should be collected from a normally distributed population, (2) observations should be independent and the dependent variable should be measured on at least and interval scale and (3) the variances in each experimental condition are similar (Ibid.). While the first two assumptions also apply for this research, the third assumption requires further data analysis. For testing the variances between groups, Field (2005) suggests the use of the Levens' test for Homogeneity of Variances. The following table presents the output of this test.

| Table 4-15: Test of Homogeneity of Variances | | | | |
|---|---|---|---|---|
| | **Levene Statistic** | **df1** | **df2** | **Sig.** |
| IQ_Timeliness | 36,505 | 2 | 150 | ,000 |
| IQ_Correctness | ,566 | 2 | 148 | ,569 |
| IQ_Completeness | ,008 | 2 | 150 | ,992 |
| IQ_Consistency | ,306 | 2 | 149 | ,737 |
| IQ_Relevancy | ,658 | 2 | 150 | ,519 |
| IQ_Reliability | 8,733 | 2 | 149 | ,000 |
| SQ_Accessibility | ,538 | 2 | 149 | ,585 |
| IQ_Overload | 5,297 | 2 | 149 | ,006 |
| SQ_ResponseTime | 2,331 | 2 | 150 | ,101 |
| SQ_Satisfaction | 1,359 | 2 | 148 | ,260 |

From the above listed homogeneity test, we can conclude that for the dimensions IQ_Timeliness, IQ_Reliability and IQ_Overload, the variances are not significantly different. This means that the ANOVA results for these dimensions should be interpreted with caution.

## 4.6.2 Information management based on the theoretical pathways

We elaborate on the cross-field study characteristics observed in line with the pathways derived in Chapter 3. The following table outlines our cross-field study

observations. Table 4-16 reflects on the extent to which the theoretical pathways we observed in practice.

| Table 4-16: Cross-case observations | | | |
|---|---|---|---|
| **Pathways provided in literature** | **Delfland** | **Gelderland** | **Rotterdam-Rijnmond** |
| Boundary spanning roles and boundary objects (e.g., IT-applications) | Partly, inter-departmental boundary spanning via the information coordinator and the whiteboards | Partly, inter-agency boundary spanning via the information manager and the CCS and ARCmap applications | Partly, inter-echelon boundary spanning via the information manager and the CEDRIC application |
| Orchestration capabilities (e.g., push and pull information between agencies, teams and echelons) | Partly, the information coordinator only pulled information based on predefined categories | Partly, the information managers shared the notes from the team meetings in the form of situation reports | |
| Advance structuring (e.g., through loose coupling and dependency diversification) | Partly, multiple boundary objects (i.e., whiteboards, situation reports) are independent and convey similar information | Yes, the different IT-applications are independent and include redundant information access and processing functionalities | No, information access via CEDRIC is limited to information already stored in its database. |
| Dynamic adjustment (e.g., through proactive scanning) | Partly based on the information categories in the boundary objects, followed by reactive information collection based on events and information needs for the tasks at hand | | |
| Reachback (e.g., direct access to information in external databases) | No clear means for reachback, use of informal contacts | No, full dependence on the ECC for information that is not available in the decision-making teams | |
| Self-synchronization (e.g., capabilities for accessing information directly) | No, full dependence on the information coordinator | | |
| Information pooling (e.g., via a dynamic portal or single window) | Partly, the whiteboards contained the aggregated information across departments. | No central information pooling, instead, several information pools emerged | Partly, only the information captured in the situation reports could be retrieved |

Table 4-16 represents both the opportunities and hurdles for our design (Chapter 6). In the Rotterdam-Rijnmond field studies, the information manager (IM) was an important role in the entire information management process, similar to the information coordinator (IC) role in de Delfland field study. While the IM role was fulfilled by relief workers that are available (and when possible, have some experience with using CEDRIC), the IC role required a relief worker with some experience in information coordination during disasters. We found that there are no clear guidelines and criteria for selecting and training relief workers for fulfilling the roles of IM and IC. Next to these roles, the ECC also played in important role in

pushing (broadcasting) information when possible and fulfilling information request from individual relief workers.

Although the IM role is focused on the generation of situation reports, we also observed several occasion in which the IM was also requested to search, validate or complete information by other members of the team. In this way, the IM and ECC functioned as information brokers between the information demand and supply. The role of information coordinator (IC) in the Delfland field study was even more central since the IC was the only operator of the whiteboards. We observed two principles used for information pulling guiding the information sharing process: agency based (e.g., in case of a fire, the commander of the fire department is questioned first) versus event/priority based (e.g., who knows something about the victims in the area?). We see that less experienced[2] information managers fully dedicate their attention to listening and typing, focusing on capturing information from the information sharing process, which is led by the chair of the decision-making team. On the other hand, the more experienced information managers are more active in the information sharing process and ask exploratory, explanatory and confirmatory questions while information is being shared. For instance, one information manager pointed out conflicting numbers on the death toll, requiring the commanders of the police and the fire department to recheck their sources. In this way, the information manager also acted as an IQ monitor.

A fire department officer (Rotterdam) or a water board official (Gelderland) played the role of plotter during the exercises. The plotter is usually outside the decision-making team and functions as low control (close to the incident). Plotters are expected to aggregate information into maps or images of the situation and share this with the information managers in the decision-making teams. The capabilities the plotter had available were similar for both cases and comprised of data visualization and map generating applications. In addition, the plotter had the capability enrich the plots by adding meta-information on the wind speed and potential hazard area. The latter capability proved very valuable for a number of the exercises in Gelderland, were the commanders of the relief agencies needed to develop a common operation picture on the area that would be flooded. In Gelderland, the decision-making team on the strategic echelon had a beamer that could project such information on the wall. In Rotterdam however, the decision-making teams on the tactical level did not have a beamer, so the chairman either sketched the situation on a large paper map or on the whiteboard based on his understanding of the plot he'd seem on the laptop screen of his information manager.

We found that the various disaster management agencies particularly collaborate and share information in multi-agency teams. Teams like for instance the COPI, ROT or GVS form the core information hubs in public safety networks, pulling and pushing information across agency and echelon borders. Depending on the safety region and the type of disaster at hand, the number and composition of these multi-agency teams vary. The exercises proved that it is difficult to pre-determine the exact configuration of organizations and the required information sources. The agencies participating in these teams need to rapidly transform from an 'autonomous' (daily-operations) mode into an 'interdependent' (disaster response) mode. In this temporary transformation process (until after the disaster recovery phase), the relief workers bring their agency specific information management practices

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[2] we asked information managers to state their experience level prior to each exercise

and applications within and outside these teams. Since the architects have tailored these IT applications to the information needs of the respective agencies in daily (routine) operations, they are often heterogeneous and incompatible. Within such teams, expertise about the relevant data and information pertaining to a disaster is highly distributed. This means that the knowledge required to effectively address a disaster spans multiple domains and specializations. It is likely that the expertise is distributed across many individuals and organizations. During a disaster, one challenge is how to bring that distributed knowledge together. The example of the stored chemicals in the Unilever building and the chemicals manager shows the unpredictable need for a specific expertise.

We have observed that relief workers often collect information objects they need after the team meetings. This means that information collection is a reactive process, after the need for information surfaces during team meeting or events in the field (e.g., explosion of a gas tank). This while there is very little time during the team meetings to collect and interpret information since this process needs to results in decisions. One example we observed was during scenario 1. As the gas leak in the Unilever R&D building developed and fire fighters needed to act, it took over 30 minutes before one the fire department subordinates mentioned that his team would need information on the chemicals stored in the building. This information was crucial for the fire fighters success, as the presence of some other chemicals could endanger their lives. Accordingly, the commander of the fire department mentioned the need for this information in the CoPI and urged the representative of Unilever in the CoPI to provide this information as soon as possible. This representative was however uncertain about the exact chemicals and toxics stored and went back to the building to collect a large dossier on the materials stored in the building. Consequently, it took almost 40 minutes before the information became available to the team.

During the exercises, we identified various information needs and flows, both across multiple levels and between multiple agencies. The information flows were ad-hoc and depended on the type of information (e.g., static information, such as location maps vs. dynamic information, such as casualty count). Although some of the information flows were formal (according to the command structure), some were informal and involved personal calls using mobile phones between relief agents. Cross-echelon information flows took place across the operational, tactical and strategic echelons of individual agencies. The ECC mediated most of the cross-echelon information flows. Noteworthy is that there the boundaries between the information demand and supply was often blurred. Relief workers that requested information at t=1 could also push information at t=2.

In each of the exercises, we found that the process of information management was a recurring yet ill-structured process. We found that the information sharing process is primarily supply driven. Similar to the OODA cycle we have discussed in Chapter 1, we observed that the relief agency commanders share information when it is there turn to speak. There are no predefined checks for dealing with poor information quality. Only when information is inconsistent (for instance regarding the exact location of the disaster), the team members raise the discussion on the quality of the information and request for further checks.

The multi-agency team, the information manager in such a team and the emergency response centers are the main components of the information management architecture. This means that these components are actively involved in the

information management process. Information coming in or going out throughout the public safety network (focused in the COPI and GVS teams) is the primary mean of combating uncertainty. Still, we did not observe a predefined or structured information management approach at the start of an event (when every actor wants to know more about what is going on). Instead, information is shared based on the "speak when it is your turn" principle. This means that in the multi-agency team, the representatives of the different agencies share information when they get the token to speak during the various decision-making rounds.

We also observed that much information was lost through cross talk: of actors focus on what information they need (pull) rather than focusing on what information is provided/pushed. As the scenarios evolved, the reliability, completeness and the accuracy of information becomes more important. Not one single actor solely has access to all the information required to independently decide or act during a disaster. Because of the various aspects of a disaster (victims, public chaos, fire, hazardous chemicals etc.), all actors have to forage for information outside their own organization. We did observe that for some important information objects (e.g. location of the disaster, hazards) decision-makers, especially the COPI/GVS leaders crosscheck the information as much as possible, via different media (e.g. personal contacts in mobile phones). The exercises showed that it is very hard to predict what information objects are required in the early stages of disaster response. As the disaster evolves, the decision-makers predict (routinely or intuitively based on previous experience) what kind information that need. This means that the completeness of information is correlated to the time/evolution of an event. The complexity of a disaster (many events, actors, interrelations, information objects) requires a high level of (individual) information processing. The introduction of technology (CEDRIC) helps relief workers in processing incoming and different data sets into useable information. The actors were however still very concerned about the usability of such technology in the field.

Situation reports were an important carrier of information between the different teams across the three field studies. As such, these reports acted as boundary spanning object. The boundaries included organizational boundaries (inter-organizational) and echelon boundaries (intra-organizational). These situation reports that were generated and send over different timeframes included essential information on the status of response efforts. While there was no universal time between situations reports, information managers tried to send out situation reports by the hour. One major issue regarding the generation of situation reports was that some information which was shared in these reports were often outdated by the time the reports were received and consulted by the members of the receiving team. Since it was not clear what information was outdated, the situation reports had a dangerous side effect on the receiving team. In the Rotterdam case, multiple information managers were frustrated by having to generate each situation report repeatedly and not be able to update changed information in earlier reports. This because reporting software they used did not provide capability to label information as new and updated for instance by bolding or highlighting information in previous situation reports. Moreover, the fact that the situation reporting software they used is a thin client internet application, which frequently failed if the wireless internet connection is lost, frustrated them because they had to retype a new document and did not know which information was most timely.

Although not mentioned in any of the handbooks for disaster management, we did observe some occasions in which the relief workers searched for information directly instead of requesting the information via the ECC. A specific example is the level of hazard of a specific chemical found on board of one of the ships in Rotterdam. While the name of chemical was known and shared by the captain of the ship, the relief workers did not know for sure of this chemical was flammable. The advisor on hazardous materials borrowed the laptop of the information manager and conducted a Google search. In this case, we consider the laptop with internet connectivity within a decision-making team as a form of empowerment. Note that it is not standard practice to have such a laptop. Even though the many search results required some time, the advisor was able to determine the flammability of the chemical with a shorter response time then would be possible with an information request via the ECC.

The field studies provide evidence of the use of different applications for information management in practice. Here we see a mix of specialized (single functionality) and multi-purpose (several functionalities) applications. CCS, ArcMap and the whiteboards are examples of specialized applications that only provide only one single functionality for the operator. On the other hand, we observed the use of multi-purpose applications such as CEDRIC and FLIWAS which provide several functionalities including situation report generation, search, document storage, attachment sharing and situation plotting. These multi-purpose applications are developed from a centralized architecture view, dictating the one information system application provides all the functionalities (i.e., services) needed for information management in the PSN.

We found that apart from the distributed expertise, the relevant data sources were highly distributed as well. Considering all the elements in the two different scenario's (chemicals, demonstrations, ships, congested roads, hospital capacity etc.), there were a more than six different data sources that were relevant. However, just locating these sources proved to be a significant challenge since the information relevant to a disaster was distributed over hundreds of organizations. These organizations varied between the public organizations (police, fire department, GHOR) and private organizations (Unilever, Shell etc.) in the harbor area. Both the distribution of sources and expertise during a disaster made it is difficult to plan for the type of information needed for all possible disaster. Apart for some of the public disaster management organizations, the potential participants (such as the Unilever, Shell, Hospital and Cruise Ship Operator) in the decision making process, cannot be predicted. Moreover, the information sources of the potential participants that could be crucial during disaster management cannot be determined at forehand. We observed that the participants on the Cop level and especially on the regional (ROT) level also changed over the course of the disaster and the phases of disaster management.

During the COPI exercises, much of the data that was integrated and disseminated is heterogeneous, both structurally and semantically. This is because data from a large number of different domains and organizations is needed to execute disaster management processes. For instance, in the case of the COPI exercises; data was required about persons—both about victims and about relief personnel. In additions, data was necessary about damages to buildings, ships, infrastructure and stored materials; weather data (wind speed and direction); geographical

data about roads and other landmarks as well as satellite imagery that can be used for damage assessment; logistics data about vehicles, delivery times.

Something we have observed in the three field studies is the lack of ability for the multi-agency teams to access third party databases on the fly. For instance, during the flood exercise in Gelderland, a potentially dangerous chemical spilled from of the ships affected by the dike break. In order to assess the potential hazards and determine the necessary counteractions, the relief workers wanted to know what chemicals were on the ship. This data was available in the database of the shipping company, but was beyond the direct reach of the relief workers that needed this data for completing their tasks. Consequently, relief workers had to wait for two hours before this information was available via the ECC. In Rotterdam, we observed a similar case, but this time the relief workers did not use the ECC to find information but searched themselves by using Google to find information on hazardous materials. Even though this approach was much quicker, relief workers had some problem of filtering the information in Google using the correct search terms and could not guarantee the reliability of the information they found and used.

### 4.6.3 Limitations of our field studies

The interpretation of our results is subject to certain limitations. First, our empirical results must be considered in the context of the particular field study locations included in this chapter. The exclusive use of Dutch respondents has the advantage of excluding unwanted confounding factors resulting from cultural differences; yet the generalizability of the results is probably reduced. Moreover, the samples of respondents only include relief workers that were present during one of the exercises, and do not reflect a true random sample. Second, in an effort to develop a reasonably parsimonious understanding of multi-agency management in practice, models reported in the literature could not be included. For instance, future research might include additional antecedents to shared information quality. Third, as with most all empirical studies, collecting similar data from more types of PSNs would have been preferable. We hope that other researcher will employ our data collection instruments in different settings. The use of more (three to five) observers during each exercise would have enhanced the study. Finally, the use of field study data allows us to examine only a "snapshot" of the impact of information systems on IQ and SQ. Perhaps future studies will consider the use of longitudinal data, which would reveal the dynamic of this phenomenon over an extended period.

### 4.7 Summary

This chapter presents the findings of our field studies in the Netherlands and demonstrates the power of combined methods in analyzing complex PSNs. We discussed the configuration and performance of three different information systems for disaster response. We conducted three field studies: Rotterdam-Rijnmond, Gelderland and Delfland. Throughout these field studies, we set out to answer three sub-questions.

The first sub-question (2a) asked about how multi-agency teams manage information during disaster response in practice. As essential part of the field studies, we observed 22 different disaster response exercises in the Netherlands. The exercises were observed based on an observation protocols crafted for studying the information management process, roles, capabilities and information/system quality issues. We investigated this question by collecting, analyzing and triangulating

observational data, available documentation, informal talks with relief workers during training exercises and discussions with exercise trainers before and after training exercises. We observed that that inter-agency and inter-echelon information management takes place via multiple channels (voice, text and visual). Moreover, the roles and capabilities for inter-agency and inter-echelon information sharing are designed for hierarchical operations and are non-adaptive to situational needs. In general, information is shared according to hierarchically organized command and control structure. This hierarchy of information sharing resonates with a functional hierarchy. Commander brief subordinates on a very limited 'need to know' basis and are often oblivious to the wider context and significance of their actions. This reflects the belief that the most effective repression operations are carried out under rigid control exercised from a hierarchical command structure. In such hierarchy-based information system architectures, subordinates should always report only to their commanders and the emergency control room is limited in its capabilities to assure IQ and SQ.

Considering the various information system architectures in practice, the second sub-question (2b) asked about what level of IQ and SQ existing architectures assure for relief workers during disaster response. We investigated this question using surveys. The surveys included IQ and SQ items that other scholars have tested in previous studies (see Lee et al, 2002). In total, we collected 177 completed surveys, of which 153 were suitable for data analysis. We prepared and analyzed the collected survey data using SPSS. The CEDRIC application in the Rotterdam-Rijnmond case allowed us to study information management using a single application. This single application based information system architecture scored relatively high on IQ-consistency, IQ-relevancy and IQ-correctness, but low on IQ-timeliness, SQ-accessibility and SQ-response time. In the Gelderland case study, we observed the effects of using multiple applications of information management. The four applications used in the Gelderland case allowed us to study information management using multiple applications. This multi-application based information system architecture scored relatively high on IQ-correctness, IQ-relevancy and IQ-timeliness, but low on IQ-completeness, IQ-consistency and SQ-accessibility. Finally, in the Delfland field study, we collected data on the use of whiteboards as non-IT enabled means for information management. The participants rated the use of whiteboards for information management high on IQ-correctness, IQ-consistency and IQ- relevancy, but low on IQ-completeness, SQ response time and SQ-accessibility. On a cross-field study level, the survey results indicate the relief workers are generally satisfied with the IQ and SQ, even if accessibility, response time, reliability and information completeness were sometimes problematic.

Chapter 4 allowed us to investigate questions 2a and 2b. Question 2c is addressed in Chapter 5, which presents the findings from the interviews with information system architects.

# 5    Expert interviews: capitalizing design experiences

*"Always listen to experts. They'll tell you what can't be done and why. Then do it."*

Robert Heinlein (American science-fiction writer, 1907-1988)

## 5.1    Introduction

The previous chapter elaborated on the information quality (IQ) and system quality (SQ) issues that we have observed during disaster response exercises. The quantitative data collected from the surveys revealed that some IQ dimensions (i.e., correctness and timeliness) and SQ dimensions (i.e., accessibility and response time) were particularly hard to assure. In addition, the previous chapter reported some observed characteristics and constraints of three existing information system architectures (single application, multi-application, and whiteboard based information management). The field studies also allowed us to gain some initial insights on the extent to which the dynamic capabilities proposed in the theoretical pathways (Chapter 4) are available in practice.

This chapter aims to extend this understanding and to broaden our understanding of measures for assuring IQ and SQ in practice. While the field studies did provide us some end-user perspective on the current information systems in public safety networks (PSNs) and the resulting IQ and SQ issues for relief workers, we still need to find out which pathways would be suitable for assuring IQ and SQ. At this stage of this research, the pathways discussed in Chapter 3 were still to conceptual for synthesizing design principles that assure IQ and SQ. Accordingly, this chapter zooms in on the third part of the second research question (2c): *What are the existing best practices of information system architects for assuring IQ and SQ?* In order to obtain a more in-depth understanding of current practices for IQ and SQ assurance, we decided to consult experts. With 'experts' we refer to senior information system architects and designers of applications for information management in PSNs. Alongside academics and policy makers, these information system architects are in fact the audience of this research. We chose to employ semi-structured interviews as method for consulting the experts since this instrument allows for in-depth, qualitative data collection. In addition, the interviews allowed us to take information system architect's perspective on IQ and SQ assurance, hence complementing the observer and end-user/relief worker perspectives taken during the field studies. Accordingly, the main objective of the interviews was to capitalize some design experiences on assuring IQ and SQ from information system architects. The strategy here was that by engaging in discussions on the occurrences of IQ and SQ problems, we could capitalize on the design experiences of the experts in addressing some of these problems. This chapter proceeds by discussing the interview procedure and findings. This chapter concludes with some reflections on IQ and SQ problems and design experiences. Parts of this chapter were published in the Lecture Notes on Computer Science (Bharosa, Janssen, et al., 2009) and the proceedings of the Sixth International Conference on Information Systems for Crisis Response and management (Bharosa, Van Zanten, et al., 2009).

## *5.2   Interview procedure*

While we have already discussed the general research strategy in Chapter 2, this section provides more detail on how we conducted and analyzed the interviews. We designed the interviews to serve two purposes: (1) gain insights in the hurdles for IQ and SQ assurance in the architectures of existing information systems (2) capitalize on the design experiences and current practices of experts. Considering these objectives, we needed to interview experts who not only have experience in designing IS for disaster response, but also use 'state of the art' concepts and solutions for IQ and SQ assurance. In total, we interviewed sixteen information system architects that were selected based on a set of selection criteria (Chapter 2). The sixteen interviews were conducted in the second half of 2008. Each respondent was interviewed in person at their office for approximately one and a half hour. Prior to the interviews, the objectives of this research and the type of topics in which we were interested were e-mailed to the respondents, to ensure that all the interviews adhered to the same general format. Each semi-structured interview began by stating the background of this research and assuring the participants that their organizational and individual identities as well as responses would remain confidential. The interviews were guided by a predefined and pre-tested (with peers) interview protocol containing open-ended topics or 'seeds' that partly guided the interviews (together with the responses of the respondents). Examples of topics include:

1. Information quality (IQ)dimensions and problems
   a. Are you familiar with IQ dimensions?
   b. Do you recognize some of these IQ problems <table 1-3>?
   c. How relevant/important do you consider these IQ dimensions as challenges in public safety networks?
2. System quality (SQ) dimensions and problems
   a. Are you familiar with SQ dimensions?
   b. Do you recognize some of these SQ problems <table 1-4>?
   c. How relevant/important do you consider these SQ dimensions as challenges in public safety networks?
3. Current information system architectures
   a. What kind of information systems do you operate or design?
   b. What are the main components of your information system architecture?
   c. What types of projects on information systems are you currently engaged in?
4. Hurdles in the current information system architectures
   a. What are the main hurdles or constraints for IQ assurance in the current information system architectures?
   b. What are the main hurdles or constraints for SQ assurance in the current information system architectures?
5. Suggested measures and current practices
   a. How do you address IQ and SQ problems? <based on the shortlist provided in table 2>
   b. Are there any measures or guidelines you use for assuring IQ and SQ?
   c. Can you give any examples of solutions or current practices?
   d. Can you recommend any current practices?

During each interview, we discussed the two main topics: (1) the occurrence of IQ & SQ related problems (when necessary, led by the examples of IQ & SQ related problems and (2) ways in which architects try to overcome such problems in their design (i.e., which measures they take). Exploring the experiences of the architects in their particular environment made it possible to gain a richer and more comprehensive understanding of IQ and SQ problems and potential solutions. Moreover, reflecting on specific IQ & SQ related problems together with the respondents proved conducive to a creative process of pathway 'shaping'. The interviews were recorded on tape so as to minimize data loss. Detailed written notes were taken during the interviews, which were transcribed within 48 hours and then returned to the participant for review and correction. The 16 interviews yielded approximately 70 pages of transcribed text. The resulting interview transcripts were then each e-mailed to the respondents, who were asked to approve them within two weeks. In this case, 'approve' means that the respondents checked the transcripts of the interview for inconsistencies, and determined whether the transcripts were a truthful account of the interview. An average of approximately 2% to 5% of the transcript text was modified; the majority of this modification involved removal of personal identification (such as names and locations) rather than factual errors regarding disaster events, decisions or communications. If significant changes were made, the corrected and completed transcript was returned to the participant for review. If analysis deemed it necessary, we contacted the interviewee in question by telephone to clarify a point or expand on a theme.

## 5.3 Data management and analysis using ATLAS.ti

We analyzed the data collected from the interviews using ATLAS.ti software, version 5.2 (www.atlasti.com). Using this software, the interview transcription and observation notes were converted into electronic versions and saved as a Hermeneutics Unit. 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. ATLAS.ti is designed to offer support to qualitative-oriented social researchers in their activities concerning the interpretation of text (Muhr, 1991) including the capacity to deal with large amounts of text, as well as managing of annotations, concepts, and complex structures, including conceptual relationships that emerge in the process of interpretation. The use of software and data coding makes qualitative data analysis procedures more systematic and guards against information-processing biases (Miles & Huberman, 1994).

The process of data analysis was retrospective, seeking to replicate findings between the cases (Yin, 2003, p. 50). The interview protocol served as the preliminary coding structure for the data. However, in line with a grounded theory approach, additional codes were created as specific themes began to surface in the coding process (Strauss & Corbin, 1990). The code structure was iteratively revised until the researchers determined that all relevant themes or issues were reflected (Eisenhardt, 1989).

The data analysis was an iterative process in the sense that data were coded and the emerging themes were explored immediately after several initial data collection activities. Several of the interview transcripts were coded repeatedly as the final coding structure emerged. It should be noted that the text was coded according to the interpretation of the researchers, rather than through matching the code with the exact words spoken by the participants. After coding was competed, re-

dundant codes were grouped into code 'families' and assigned a descriptive construct name. For example, the individual codes 'correctness', 'relevancy' and 'completeness' were all grouped into a single code family, which was then assigned the construct name "information quality" due to the relative weight of that code versus all others in the family. Weights were assigned based on the total number of respondents to mention a specific code. In order to retain the integrity of each interview's meaning, and not bias the coding process of either interviewer, this process was conducted independently for each country, with the results of these efforts compared only after code families had been created.

One of the main reasons for using ATLAS.ti is that this software permits concepts in the qualitative data to be interpretively assigned into categories (Baskerville, Pawlowski, & McLean, 2000). The network feature or causal mapping functionality of this software is then used to link coding terms, as a means of suggesting fruitful relationships to explore until "saturation" is reached—the point where new iterations produce little change to any causal relationships between the categories, especially the core category. With the linear textual data in the interview transcripts as a starting point, segmentation and coding ("textual phases") of the text alternates with the building of conceptual maps and hyper textual structures ("conceptual phase"). Another important reason for using this tool is its ability to generate network views (see figures 1, 2, 3). Using ATLAS.ti the researcher can draw actual "conceptual maps" consisting of boxes and connecting lines that depict the aggregated linkages between concepts mentioned within each interview. Within these conceptual maps, different codes and their mutual relationships can be visualized, generating an overview of relationships between the key concepts of the interview, both individually and in combination. For example, for the quotation "*many occurrences of incorrect or outdated information during disaster response could have been avoided if the data stored in the source systems would have been regularly audited*", three dyads were created including "incorrect and outdated", "data and source systems", and "incorrect or outdated information and audited". These dyads were recorded for every transcript, and were aggregated based on the total number of respondent to mention each individual dyad. Christensen and Olson (2002) recommended the development of maps that included constructs linked by one-third to one-fourth of all respondents with Figures 1, 2 and 3 thus generated using a cut-off level of 4 or more respondents (as the sample was 16 respondents).

In order to enhance the comparative power of these maps, the total number of respondents who mentioned a link dyad was displayed in addition to the conventional approach of displaying these numbers with individual constructs or topics. In interpreting conceptual maps, it is suggested that the reader begin with the central topics and follow the resulting links until an end-state is reached. By doing so, those topics considered most essential would be identified first, allowing the reader to quickly grasp the emphasis and flow represented within each mental map. Linkages between constructs represent concepts connected in the thoughts of respondents, thus adding greater insights into the relationships between each stand-alone idea. For example, following one of the more important thought patterns in Figure 5-3, starting with the "service oriented architecture" construct, we can derive that the development of service oriented architectures is especially important for assuring the flexibility of information systems (SQ) and the format of information (IQ).

## 5.4 Findings from interviews: experiences and current practices

Recall that one of the objectives of the interviews was to explore whether or not the list of IQ and SQ problems presented in chapter 1 are acknowledge as challenges for the information architects. More specifically, we wanted to know which IQ and SQ dimensions were deemed as "requirements that needed to be addressed" by the information system architects. When considering IQ and SQ dimensions (see tables 1.2 and 1.3) as information system requirements, most experts agree that the majority of these dimensions are relevant issues in public safety networks. 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 5-1: Conceptual map for the information quality requirements**



Figure 5-1 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 sixteen respondents regarded IQ assurance as a larger concern than SQ assurance, while four of the 16 regarded SQ assurance as largest concern. The most often mentioned explanation is that a system that has to process low quality information cannot 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 5-2 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 sixteen 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 5-2: Conceptual map for system quality requirements**

The interviewed experts do not reach a consensus on the existence and the need of requirements for these dimensions. A frequently mentioned addition to the dimensions of system quality is the 'robustness of the system'. Overall, experts consider larger problems in the organizational architecture than in the technical architecture. Technically, the mono-disciplinary system can be joined easily, but there are many organizational problems among the different parties involved.

### 5.4.1   Hurdles: fragmented and heterogeneous information system landscape

This table of IQ and SQ problems (chapter 1) was used to introduce the architects to these problems. Next, they were asked to share their experiences with addressing these problems in practice and developments. The interviews revealed that various information system architects try to capture similar IQ-related problems, but have different experiences with IQ & SQ related problems and how to address them. When discussing the shortlist of IQ & SQ dimensions and problems, all sixteen respondents acknowledged the occurrence of similar problems. Even though all the respondents agreed that IQ & SQ are major concerns, not all of them shared the vision that such IQ & SQ related problems could be solved, or that the highest level of IQ (i.e., 100% relevant information) or SQ (i.e., 100 % up-time) could be guaranteed. The most mentioned reason for this was the high level of heterogeneity in multi-agency disaster response networks.

As one of the respondents explained: *"In the Netherlands, each of the relief agencies has their own IS architects, who over the years have developed all kinds of customized information systems focused on satisfying their own agency specific information needs rather that (multi-agency) IQ requirements"*. Put differently, the majority of information systems used for multi-agency disaster management were actually developed for the routine operations of individual agencies. *"As a result, our disaster management systems are designed, developed and operated in a*

*very fragmented and heterogeneous way, making it difficult to address IQ-related problems that are often of a multi-agency nature".* When asked what needs to be done in order to guarantee at least an acceptable level of IQ for relief workers, this respondent suggested more technical solutions including standard message interfaces and data exchange formats, and that, for the necessary level of IQ to be guaranteed, some relief agencies would even have to abandon their legacy information technologies and adopt a standard set of interoperable technologies. While the other respondents also acknowledged the fragmentation in the current information system landscape, they were less skeptical with regard to the possibilities for guaranteeing IQ. As one of the respondent put it: *"even though we can never assure 100% IQ, assuring IQ should become one of our main priorities, and should even be a standard or practice for everyone who has a part in the design and use of information systems."*

One respondent mentioned that the different technical instruments available for relief workers operating in the strategic, management or operational echelon forms a major hurdle for assuring 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. Some respondents explicitly mentioned the importance of 'non-technology' driven solutions for IQ & SQ. Overall, the respondents agreed that design principles aimed at guaranteeing IQ & SQ were lacking.

Another notable hurdle from the interview transcripts 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 (i.e., comply with NORA, a national reference architecture for governmental ICT systems, and use CEDRIC), yet these standards are either neglected or slowly adopted because of existing regional or agency specific standards and legacy systems.

### 5.4.2 Developments and current practices

There experts mentioned three developments that will directly or indirectly affect IQ and SQ in public safety networks. One of these developments is Network Centric Operations (NCO), which is originally a concept from the military. One respondent suggested that: *"The essence of the network-centric approach is that by empowering relief workers with the information technology that allows them to collect and share information throughout the network, information management during disaster response can be improved."* Another respondent had a somewhat different interpretation of NCO: *"we should find ways to use the network of respondents more in the IQ assurance quest. For instance, if each relief workers would be able to view, add or update certain meta-data fields of information such as its timeliness, completeness and priority, recipients of information would be able to judge themselves whether or not the information is of sufficient quality or should be enriched".* In this context, enrichment would require information-processing capabilities such as information triangulation with other sources, or information fusion for completeness. Another respondent had ideas about a different potential of NCO and explained: *"Often, when we think of NCO, we only discuss information-sharing between relief organizations, but in practice information comes from beyond the borders of these organizations."* The bottom line is that information sys-

tems should at least be able to capture information beyond the network or relief agencies. The majority of respondents acknowledged that the Dutch Government, which has even funded the development of a software application called CEDRIC to enable NCO, heavily favored this concept. With CEDRIC, relief workers on various response levels can digitally share information in various formats, including situation reports and geographic maps (Bharosa, Janssen, et al., 2009). Nine of the respondents argued that using NCO would help address some IQ-related problems. The idea here is that, if everyone has the means to access and share information directly, information could flow more quickly between relief agencies, reducing the likelihood of the information becoming be outdated. However, some of the interviewees were very skeptical about this concept and warned, *"NCO should not be considered as a single solution to all the problems regarding information management and IQ assurance"* and *"NCO could create information mess and overload."* Moreover, some interviewees emphasized that relief workers do not need yet another *"new"* technology or system in a technology landscape that is already very complex. *"The pitfall for a PSN here is that they think the introduction of Cedric will suddenly solve all the information related problems. We should not forget that information management is still a human process, so we need to invest in training people."*

A more technology-related development is the evolution of Service Oriented Architecture (SOA), which, as a dominant architecture design style, was important with regard to improving IQ. One respondent explained, *"SOA allows for flexibility and interoperability without technical integration, enabling data access across relief agencies without the need for specific data formats or standards."* Often, relief workers have minimal capacity hardware devices and limited Internet connectivity, so they need lightweight but adaptable service portfolios depending on the type of disaster (context). *"This is where SOA can play a significant role"* one respondent explained, *"We should not burden relief workers with predefined sets of applications which may or may not be appropriate for dealing with the situation at hand."* Instead, he suggested, *"systems need to allow relief workers to create and adapt their own application portfolio, so they can delete or add application services whenever and wherever they need it."* However, according to some of the respondents, the benefits of *"SOA may be overrated,"* especially if there are no agreements on data-sharing rules and security procedures.

An organizational development aimed at assuring IQ was the introduction of an information manager function in disaster decision-making teams. The majority of respondents suggested that the recently introduced role of the information manager in Rotterdam-Rijnmond is a first step in assuring information access within multi-agency teams. *"This information manager should act as a boundary spanner between agencies and orchestrate information flows between demand and supply, not for all but only for crucial information needs."* Given the right set of tools and functionalities, the information manager can act as an orchestrator that determines who needs specific information and who does not, making it possible to assure relevance and to minimize information flows. *"For this to work, we are currently working on a pre-classification of information objects depending on the relevance of the content for a specific situation. Location information, for example, is always relevant to all agencies, whereas information on the name of gas stored in a building is only relevant to the fire department, except when this gas is known to be dangerous or explosive, in which case the information is relevant to*

*everyone."* Accordingly, the information manager needs to be able to determine and handle information in different ways. The experts were not consistent on the tasks and functionalities of the information manager in the current situation. Finally, at least half of the respondents stated that policy-makers, operators, and fellow information system architects mainly focus on assuring IQ during a disaster itself. *"We as a community also need to think about ways for assuring that information is correct before a disaster happens."* As one of the respondents explained: *"many occurrences of incorrect or outdated information during disaster response could have been avoided if the data stored in the source systems would have been regularly audited".* Another respondent added that: *"garbage in is garbage out regardless of the advanced information technology being used, so we need to take actions for IQ assurance not only during disasters, but also before they occur".* This suggests that principles should focus on assuring IQ before and during a disaster.

### 5.4.3   SQ is going concern, IQ is future concern

Overall, the information system architects focused on assuring SQ dimensions instead of IQ dimensions. *"Often, we focus on improving the reliability, security and user-friendliness of current systems,"* one respondent stated, acknowledging that the current focus is on SQ assurance instead of IQ assurance. One explanation for this can be found the 'Wet Veiligheidsregio's', a recently accepted law governing the development of regional disaster response institutions. According to this law, relief agencies in the same geographical regions need to have interoperable information systems and policies by the end of 2010.

In order to comply with this law, information architects are required to focus on either adopting a nationwide application (called CEDRIC) or advance the quality of their own application. Either way, much more emphasis is on SQ than on IQ. This kind of technology push often forces information architects to focus on the more technical characteristics and quality dimensions of their information system architecture. Another explanation is that information system architects consider SQ assurance an easier to address problem than IQ assurance. Whereas the design of the information system architecture can address some SQ challenges (i.e., response time and interoperability), the assurance of IQ requires more significant changes to the architecture of existing information system, including roles, tasks and policy changes.

## 5.5   *Shaping pathways: suggested measures for assuring IQ and SQ*

Based on the collection of interview transcripts, we could start with more advanced qualitative data analysis. Figure 5-3 outlines some of the relations found through the interview analysis software, focusing specifically on the relationship between IQ & SQ related problems. This figure also depicts some measures for assuring IQ and SQ provided by the experts. Usually, the software structures the IQ and SQ dimensions (as dependent variables) at the center of the conceptual maps, whereas the principles and solutions (as independent variables) are placed at its boundaries. Because principles are an abstraction of solutions, they can comply with multiple solutions. CF stands for Code Family, indicating the various problems related to IQ or SQ. The dashed lines indicate the IQ & SQ related problems in the respective code family. Note that the number between the brackets indicates the number of respondents who mentioned this issue.
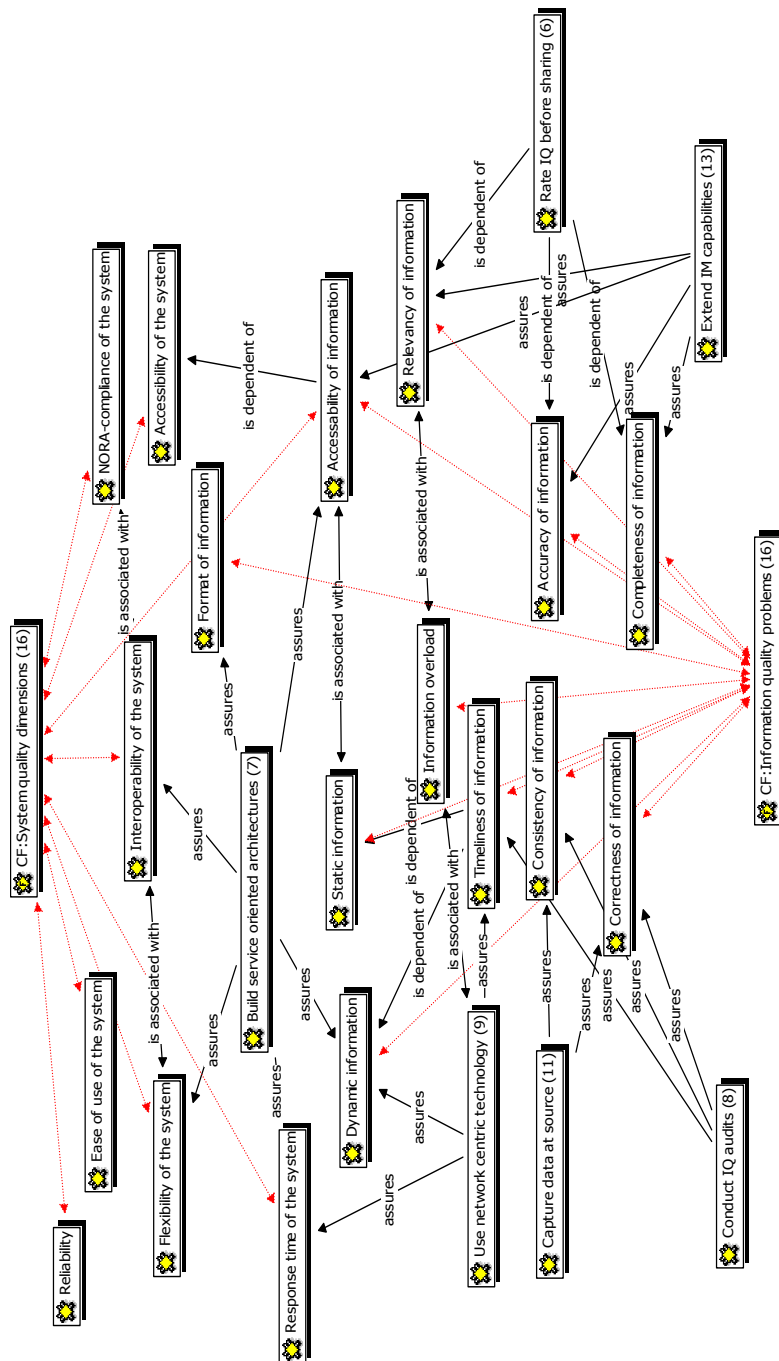
**Figure 5-3: Conceptual map for the IQ and SQ problems and suggested measures**

Throughout the interview transcripts, ATLAS.ti recorded several suggestions, including the maximization of information flows via information managers (mentioned by 9 respondents), the use of IQ audits in order to detect and remove incorrect or outdated information before a disaster (mentioned by 8 respondents), the proactive anticipation information needs (mentioned by 6 respondents) and the enrichment of information objects by adding meta-data (mentioned by 5 respondents). The following table summarizes the suggestions for IQ and SQ in PSNs derived from the interviews with the architects, thus capitalizing their design experiences and current practices. To date, there is no single theory (e.g., NCO) or information technology (e.g., CEDRIC) addressing all of the potential IQ and SQ issues. The brackets refer to the ID of the interviewees listed in Appendix-C.

| Table 5-1: Suggestions for IQ and SQ assurance | | |
|---|---|---|
| **Design experiences** | **Targeted IQ issues** | **Mentioned by interviewees** |
| Conduct annual IQ audits (garbage in is garbage out) | Incorrect, incomplete, inaccurate, and outdated information in agency data sources. | 8 out of 16 (mentioned by 1, 4,5,6,8,9,11 &15) |
| Extend the capabilities of the information manager | Correctness, timeliness, accessibility, information overload, bridging interdependencies between relief agencies. | 13 out of 16 (mentioned by 1,2,3,4,5,6,7,8,10,11,12,13 & 14) |
| Develop an information system with reachback capabilities | Response time, interoperability, reliability, accessibility, timeliness | 9 out of 16 (mentioned by 1,3,4,5,7,8,13,14 &16) |
| Build modular service oriented architectures | Information access, flexibility, reliability, response time, dealing with unknowns or unprecedented information needs. | 7 out of 16 (mentioned by 1,3,4,5,9,10 & 11) |
| Promote and train IQ assurance as standard of practice | All IQ-related problems | 16 out of 16 (mentioned by all the respondents |
| Capture information at the source and make the source of information responsible for updating the information | Inconsistency, noise, information object version control, reliability | 11 out of 16 (mentioned by 2,3,4,5,6,7,9,10, 12,14,16) |

Table 5-1 outlines six different suggestions for IQ and SQ assurance. Some conditions need to be satisfied to make these measures work. Firstly, the information infrastructure (i.e., Internet, hardware) up time should be near 100%. Secondly, the information manager should have knowledge (at least at a basic level) of the processes and information needs of the various relief agencies. Finally, private agencies (i.e., cargo shipping firms) should allow for role-based access to their databases, for instance using SOA and web-service technology.

## *5.6 Summary*

This chapter reports the findings of interviews that focus on answering question 2c (*what are the existing best practices of information system architects for assuring IQ and SQ?).* Generally, the interviewed architects recognized and confirmed the occurrence and severity of the IQ & SQ related problems discussed in the previous section. Almost all the respondents mention that the information systems are designed, implemented and operated in a very fragmented and heterogeneous way, making it hard to cope with IQ and SQ requirements. The reason given for this is that in the Netherlands, each of the relief agencies has their own information system architects, who over the years have developed all kinds of information systems focused on satisfying local, intra-agency requirements rather that regional or national IQ and SQ requirements. In addition, some information system architects mentioned that they have designed many of the existing information systems for mono-agency and routine (predefined) information management. As such, we could explain why most of the respondents were engaged in more efforts (i.e., projects) focusing on improving SQ (e.g., interoperability and ease of use) and so few efforts for improving IQ. Moreover, we noticed that some respondents assumed that improving SQ would also lead to IQ assurance. While for some cases this may be true (e.g., improved SQ response time can also lead to more IQ-timeliness), most of the respondents acknowledged that assuring IQ dimensions such as completeness and relevancy would require more than technology development. Returning to the research question we set out to investigate in this chapter, the interviewees indicated three main best practices: (1) network centric operation (2) service-oriented architectures (SOA) and (3) the introduction of an information manager as boundary spanner between different agencies.

The interviews with the information system architects are an important prerequisite for entering the design cycle (Chapter 6). While Chapter 3 (knowledge base) and Chapter 4 (field studies) helped us in understanding the hurdles and pathways for assuring IQ and SQ, the interviews helped us to understand the best practices and needs of the information system architects, who are one of the audiences of this dissertation. The most important insight we gained from the interviews is the need for developing information management capabilities that are dynamic enough to assure IQ and SQ during disaster response. Since the architects work in a multi-actor environment lacking mature and proven technologies and full of different preferences and needs, commonly accepted and technology independent, design principles would help to assure IQ and SQ over time. The next chapter proceeds by explaining principle-based design and integrates the findings of the previous three chapters in a design theory for assuring IQ and SQ.

# 6   Netcentric information orchestration: a design theory

*Society cannot afford to prepare for every eventuality, but it can create a foundation on which an effective response is quickly constructed".*

Yigal Arens & Paul Rosenbloom, Communications of the ACM, 2003

## *6.1   Introduction*

The statement above by Arens and Rosenbloom (2003) captures the main premise of this chapter. This chapter reports on the design cycle in our design science research. This cycle integrates the findings from the rigor cycle (Chapter 3) and relevance cycle (Chapters 4 and 5) and precedes the evaluation cycle (chapters 7 and 8). As discussed in Chapter (3), the available kernel theories provided in the literature do not provide directly applicable principles for assuring information quality (IQ) and system quality (SQ) in public safety networks (PSNs). Nevertheless, these kernel theories do provide some theoretical pathways that can help in synthesizing the design principles we are looking for. For instance, Coordination Theory provides the pathways of advance structuring and dynamic adjustment in order to manage information flows in complex and uncertain environments. The emergence of information technology (IT) enabled orchestration of information is also a promising pathway for coordinating information management activities of heterogeneous and distributed agencies in concert. In addition, network centric operations (NCO) theory suggests the development of self-synchronization and reachback capabilities when operating in turbulent environments.

However, the literature on coordination theory and NCO from which we have surfaced these pathways leave them somewhat generic, making it difficult to synthesize the concise and explicit design principles for assuring IQ and SQ. It is in this chapter that we draw on the combined findings from our theoretical foundation (chapter three) and empirical foundation (chapters four and five) in order to synthesize design principles. Following this process, this chapter sought to answer the fourth question of this research, *which design principles can we synthesize from the knowledge base and empirical data for assuring IQ and SQ during multi-agency disaster response?*

In this chapter, we elaborate on the synthesized set of design principles we capture under the term 'netcentric information orchestration'. We have chosen to coin our set of design principles in this way because the principles have their roots in both NCO and IT-enabled orchestration. This chapter proceeds by elaborating on our approach to employing principles of information system design. Next, we will discuss netcentric information orchestration as a design theory, followed by an elaboration on which IQ and SQ requirements the stakeholders (e.g., information system architects) can assure when employing the prescribed design principles. We evaluate the resulting set of design principles on their technical feasibility (Chapter 7) and their ability to assure IQ and SQ for relief workers in a quasi-experimental gaming-simulation (Chapter 8). Parts of this chapter were published in Bharosa & Janssen (2009) and Bharosa, Janssen & Tan (forthcoming).

## *6.2   Principle-based design*

Albert Cherns (1976) was among the first in the academic community to suggest the use of principles. Principles are particularly useful when it comes to solving ill-structured or 'complex' problems, which cannot be formulated in explicit and quantitative terms, and which cannot be solved by known and feasible computational techniques (Simon, 1996). These kinds of problems are complex because they are often socio-technical in nature or because they occur in socio-technical systems (Clegg, 2000). An information system is an example of a socio-technical system, as both humans and technology are needed for the system to exist and function (Bostrom & Heinen, 1977b). In contrast to traditional computer-based systems, socio-technical systems include both human actors and software components, and normally are regulated and constrained by internal organizational rules, business processes, external laws, and regulations. This implies that the technical and social aspects of a system are interconnected, that neither should take logical precedence over the other, and that they should be designed together (Klein, 1994).

*Principle-based design* (PBD) can be viewed as a variation of the prescriptive design research paradigm that should result in "a prescriptive theory which integrates normative and descriptive theories into design paths intended to produce more effective information systems" (Walls, et al., 1992). We consider PBD as a specific form of the more general design research methodology that focuses on extracting principles with regard to the elements of a system without explicitly referring to solutions. This does not mean that principles need to be vague. Rather than resulting in complete and ready to implement artifacts, PBD should result in principles that purposefully and assertively support architects in a network of actors with the (re-) designing and use of Information Systems (IS). Because principles are generic by nature and thus do not constrain designer creativity or possible solutions, they provide architects with freedom in designing and using artifacts based on the needs of their own organization. This level of freedom is especially important when information system architects are dispersed among heterogeneous agencies within a disaster response network. In addition, PBD aims at encouraging organizations to start right away with bringing their current practices in line with the principles immediately, leaving room for continuous improvement over time. This approach emphasizes "doing the right thing" by whatever means the information system architects feel is most appropriate given the circumstances. In contrast to requirements and constraints that keep changing over time (Gibb, 1997), principles are intended to be useful over a longer period of time, especially since they are independent of technologies actors, which do change over time.

Because PBD focuses on goal attainment rather than compliance (in the case of rules) and because the actors are free in implementing the principles, the expectation is that there will be more commitment and less resistance in multi-actor environments. As such, we argue that PBD is especially suitable for designing information systems that need to operate in task environments consisting of:

1. multi-actor organizational networks (i.e., police, fire department, ambulance, etc.) where each actor has different sets of goals, processes and supporting IS and yet are mutually interdependent in terms of information sharing and decision-making;
2. non-routine task environments involving unfamiliar events and processes;

3. multi-audience environments (principles used by architects, ICT-experts, managers and operators),

4. environments where not all the aspects of a complex problem can be predicted and specified in advance, and;

5. environments where the range of (technical) solutions and alternatives is heterogeneous and dynamic in nature.

Considering previous work (e.g., Bigley & Roberts, 2001; Comfort, Ko, et al., 2004; Fisher & Kingma, 2001; Turoff, et al., 2004), we can argue that multi-agency information management during disaster response takes place under the five characteristics listed above. Having stated the context for which PBD is suited, we proceed with a discussion on principles in the next section. Principles have been defined in various ways and they have been used interchangeably with other problem solving notions, including laws, patterns, rules and axioms (Maier & Rechtin, 2002). Housel et al. (1986), for instance, define principles as "generic prescriptions for the design and implementation of information systems". From an engineering perspective, Gibb (1997) defines principles as "rules of thumb that guide the choices and actions of engineers". From a MIS perspective, Richardson and Jackson define principles as "the organization's basic philosophies that guide the development of their architecture." In the area of information technology (IT), the Open Group have defined design principles as "general rules and guidelines, that are intended to be enduring and seldom amended, that inform and support the way in which an organization sets about fulfilling its mission" (TOGAF, 2004). It may be clear that, thus far, there is no uniform definition available. However, these definitions imply that principles are normative or prescriptive in nature, and that they are meant to give direction for the design of IS, which is why we define principles as '*normative' and 'directive' guidelines, formulated towards taking action by the information system architects.*

Compared to principles, requirements and constraints have a different impact on the design process. When specifying the concept of requirement, scholars (e.g., Darke & Shanks, 1996; Gibb, 1997) usually formulate requirements as "the artifact should be or needs to" statements, while constraints are often formulated as "the artifact is allowed or not allowed to" statements. Often, requirements include the explicit individual stakeholder needs, regardless of the overall system needs, while constraints cover the explicit conditions arising from general organizational, government and industry standards. Therefore, all requirements are in natural conflict with all other requirements in their attempt to claim common resources (Gibb, 1997). Principles capture prescriptive and directive guidelines that architects can use to design information systems within the framework of requirements and constraints. Principles draw on the experience of IS architects and include their 'proven practices of the past'. Whereas requirements and constrains often involve individual systems, principles are included in an ISarchitecture to ensure that all further developments and improvements adhere to these principles (e.g., Richardson, et al., 1990).

The use of principles determines the effectiveness of an IS. As a result of their intrinsic non-contextual nature and general applicability, principles cannot provide readily available solutions to specific design problems (Hemard, 1997). Rather than being offered as finished products, their articulation helps clarify where some of the gaps in our knowledge exist (Clegg, 2000). Therefore, the use of prin-

ciples is intended to select and apply the most appropriate knowledge for specific design and development tasks (van den Akker, 1999).

## 6.3 Drawing on the theoretical and empirical foundations

Due to the high level of specialization and distribution of work during disaster response, relief agencies operate in a fragmented mode across multiple functional, geographical, hierarchical, and professional boundaries. In such contexts, orchestrators are necessary for the coordination of information flows and objects between multiple agencies. We define orchestrators as individuals empowered with information technology (IT) enabled capabilities for inter-agency (horizontal) and inter-echelon (vertical) information management in a network of agencies. An information system architecture consisting of orchestrators is heterarchical because it includes elements from hierarchical and network based information systems.

Scholars such as Kapucu (2003) have characterized heterarchies as a form of organization resembling a network due to the lateral coordination of organizational diversity and a distributed intelligence negotiated across multiple evaluative criteria. In these types of flatter structures, the underlying assumption is that no single individual understands the whole problem, but that each member of the organization likely has insight and a responsibility to act on the best knowledge available. Flatter structures are able to reallocate their resources and personnel more quickly and efficiently, and move more effectively toward self-organization. The weakness of such organizations is that they depend upon fully functioning information systems with well-trained personnel who are capable of acting on their own initiative in ways that are consistent with the system's goals (Comfort, 1999). This brings us to the first characteristic of orchestration, the high level of IT-support needed for inter-agency and inter-echelon information management. The term "heterarchical" indicates that there is no hierarchy of information managers. Heterarchical control structures have distributed local autonomous entities that communicate with other entities without the master/slave relationship found in a hierarchical architecture. According to Dilts et al. (1991) the field of distributed computing is "a source for a number of justifications for the principles of heterarchical control architectures".

A useful analogy for orchestration lies in the centralized market concept (Malone, 1987). "In a centralized market, buyers do not need to contact all possible sellers because a broker is already in contact with the possible sellers" (pp. 1323). This centralization of decision-making means that substantially fewer information sharing connections and messages are required compared to a decentralized market or pure network. A well-known example of a centralized market is the stock market. People who want to buy a particular stock do not need to contact all the owners of shares of that stock; they only need to contact a broker who is also in contact with people who want to sell the stock. This model for coordination resembles Baligh and Richartz's (1967) model of a market with a "middleman as a pure coordinator" (pp. 123). In addition to the buyers and suppliers present in a decentralized market, we assume that there is also a "broker" (or boundary spanner) for each type of task processor. An orchestrator can coordinate all the task processors of a given type and thus plays the role of a 'information manager'. Like Baligh and Richartz, we assume that (1) the orchestrator has a communication link to each information requestor (i.e., relief worker) and each supplier of the appropriate information and (2) tasks are assigned to the "best" available supplier (i.e., update

source information). This is particularly true for information systems in the disaster management domain since relief workers can simultaneously act as information producers and consumers of information.

Boundary spanners, i.e. individuals who operate at the periphery or boundary of an organization, relating the organization with elements outside it, can perform the tasks related to netcentric information orchestration. On a general level, boundary spanning can be seen as the activity of making sense of peripheral information that is perceived relevant to expand the knowledge at the center of a given organizational context (Lindgren, et al., 2008). The difference with the traditional form of boundary spanning lies in the high reachback (wide accessibility and geographical reach of the information technology used). As such, orchestration is an information coordination activity aimed at linking new, typically environment related information to prior knowledge for gaining situational awareness. Essentially, these individuals scan the environment for new information, attempting to determine its relevance vis-à-vis information already assimilated in the organization. In this boundary-spanning process, the individual, the organization and the environment are parts of a network of interactions and organizational knowledge creation (Cohen & Levinthal, 1990).
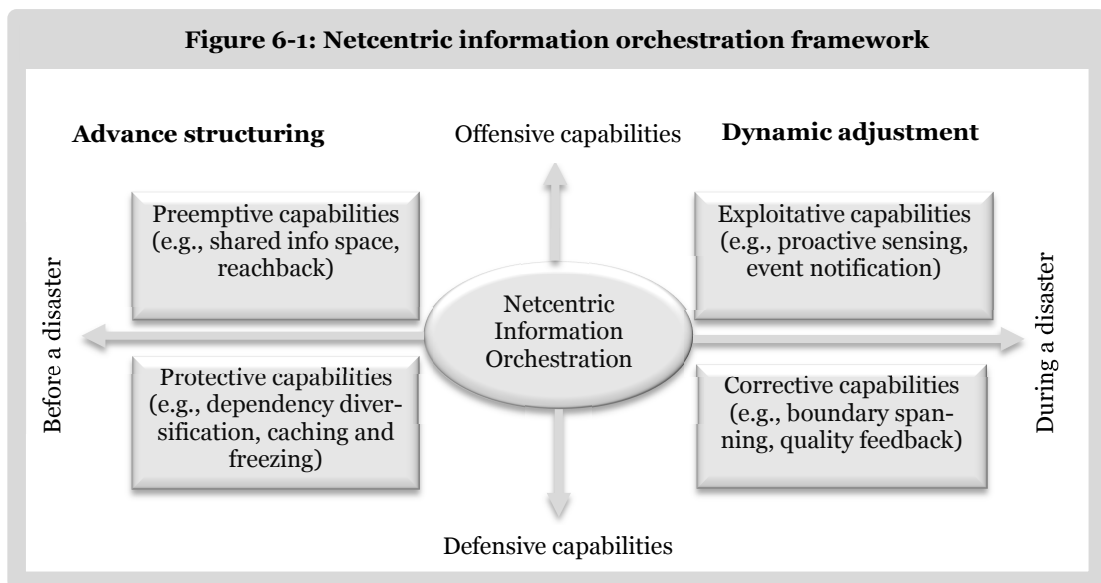
In order to maximize the benefits of orchestration, boundary spanners require a high level of reachback and self-synchronization. A key prerequisite for these capabilities is the availability and use of information technology. As a result of the high level of reachback, team members can enjoy positive resource asymmetries (Gnyawali & Madhavan, 2001). From a structural holes perspective (Burt, 1992), the orchestrator bridges the structural holes (gaps in information flows) that exist between multiple relief agencies in a public safety network. By filling the existing structural holes orchestrators enhance their control of the information that flows between relief agencies, and hence can accrue information benefits (Gnyawali & Madhavan, 2001). For instance, the orchestrator may have access to information about the resources and capabilities of the police department, or the information needs of a fire department. A capability is a set of specific and identifiable processes (Eisenhardt & Martin, 2000). According to Tushman (1977), such information gathering and assimilation is associated with specific boundary-spanning roles at different stages in the innovation process. This allows for the fulfillment of functions beyond that of storage, integration, and brokering. A public safety network can have multiple information orchestrators on different levels. Each orchestrator can fulfill one or more functions and different roles (such as we have observed in the field studies, orchestrators can be information managers, plotters, or quality monitors). Some proposed IT-enabled capabilities for information orchestration include: coordination of information, information inventory and interoperation of information services (Janssen & van Veenstra, 2005).

As stated, orchestration is not a new concept. Drawing on its original characteristics, this research extends the notion of this concept by emphasizing what is being coordinated (information and information management processes) and where the coordination occurs (heterarchical coordination throughout echelons in the network). We define netcentric information orchestration *as a heterarchical form of inter-agency and inter-echelon information management in a PSN supported by a specific set of roles and IT-capabilities related to the collection, enrichment and sharing of high quality information.* We discuss the IT- enabled capabilities necessary for orchestration in the next section.

## 6.4    A framework for information orchestration capabilities

Drawing on the pathways listed in chapter four and our field study findings, we conceptualize netcentric information orchestration as a two-stage process for assuring IQ and SQ. The stages we use are advance structuring and dynamic adjustment. These stages require either offensive (preemptive and exploitative) or defensive (protective and corrective) capabilities for assuring IQ and SQ. Figure 6-1 illustrates the stages of netcentric information orchestration. According to figure 6-1, advance structuring and dynamic adjustment require four set of capabilities for assuring IQ and SQ. We postulate that heterarchical form of information management will allow subordinate relief agencies to adjust and adapt quickly and easily to deal with changing situations or unforeseen events and circumstances. When empowered with these capabilities, orchestrators can retain the strengths (defined command relationships, efficiency, and control) of a bureaucratic hierarchy, enabling preplanning in the more predictable aspects of disaster response, yet, also permit the adaptability needed to fulfill information needs during dynamic and unstable disaster situations.



Figure 6-1: Netcentric information orchestration framework

Advance structuring refers to a-priori structuring of inter-organizational information flows and inter-connected processes, such that relief agencies can reduce the effort involved in adjusting to the changing task environment. As relief workers do not have to collaborate and share information during routine, non-disaster situations, there is often only a weak relationship between such agencies. Advanced structuring includes long-term relationship building amongst relief agencies prior to and during a disaster. Scholars have already underlined the need for advance structuring when it comes to disaster response. Pearson and Clair's (1998) for instance predict the that response organizations will have greater success if prior to the crisis event focal organizations build alliances and coordinate activities by sharing information and plans with external stakeholders. Horsley and Barker (2002) made similar suggestions within their public agency model. Their

model predicts greater success if information is disseminated quickly, accurately, directly, and candidly to critical stakeholders, including the media. Advance structuring requires preemptive and protective capabilities for structuring inter organizational information flows for instance by reducing task interdependence through loose coupling (Tan & Sia, 2006), or mitigating resource dependency by diversifying resource allocations (i.e., creating alternative information sources). Loose coupling reduces the need to coordinate information exchange and flow in a dyadic relationship, while dependency diversification generates alternative options to mitigate overdependence on critical resources. Such capabilities should result in higher adaptability. From an information architecture perspective information orchestration requires an extra layer is inserted the client and the server (Wiederhold & Genesereth, 1997). Examples of capabilities that can be leveraged through advance structuring include reachback (the ability to access resources that are not locally available) and caching (the ability to freeze data entry modules in applications so that information need not to be lost during (temporary) infrastructure failure.

**Table 6-1: Comparing three information management ideal types**

| Characteristics | Traditional approaches | Information orchestration | NCO |
|---|---|---|---|
| Ideal type for coordination | Hierarchical information coordination | Heterarchical information coordination | Peer –to- peer coordination |
| Level of centralization | High | Moderate | Low |
| Information receiver and sender tasks | One or multiple predefined individuals or groups | Role and specific information sharing and coordination | Network, everyone can push, pull and process information |
| Information flows | Follows the hierarchical chain of command (grip levels) | Situation and need driven dissemination | Widespread dissemination |
| Network configuration | Hub and spoke, publish and subscribe | Smart pull and smart push, information posting | Relational |
| Interdependencies | Pooled | Sequential | Reciprocal |
| Triggers | Input/output, procedures | Events and demand | Events |
| Coordination mechanisms | Coordination by standards plan, routines, meetings. | Advanced structuring (e.g., information pool) and dynamic adjustment (e.g., feedback) | Mutual adjustment and improvisation |
| Information sources | Agency specific, intra- agency systems | Variety of information sources, inter-agency data access | All possible sources need to be accessible |
| Service portfolio | Application depended, static, fixed | On the fly service composition | Actor/agency specific |
| Mode of operation | Reactive (push required information) | Proactive and protective (anticipate information needs) | Reactive |
| Coupling of elements | Tight | Tight with slack | Loose |

Table 6-1 presents the differences between the three main coordination approaches we discussed in this dissertation, where information orchestration is aimed at taking leveraging the advantages hierarchical information coordination (e.g., clear authority structure, standardization, specialization and formalization), and network approaches (e.g., reachback, adaptability and self-synchronization).

Complementary to advance structuring, dynamic adjustment requires the real-time reconfiguration of inter-organizational information sharing processes and resources in accordance with the changed disaster environment. The primary theoretical basis for dynamic adjustment is the learning-based sense and adapt paradigm (Haeckel, 1995). Sambamurthy et al (2003) suggest that dynamic adjustment is achieved by enhancing feedback in a changing environment through sensing and adapting making it a two-pole strategy. In sensing capability, IT-supported orchestrators become more informed and forward-looking, and have more time to adapt, through feedback, quick learning and constant environmental scanning. Examples of capabilities that can be leveraged through dynamic adjustment include proactive sensing (ability to anticipate information needs) and quality feedback (ability to rate the quality of information shared). The information-processing tasks of orchestrators include accessing of appropriate resources, data selection, format conversion, bringing data to common abstraction levels, matching and integration of information from distinct sources, and preparing information and descriptive meta-information for relief worker customer's workstations, including focusing, filtering, and summarizing. The main objective is to match the demand for information as much as possible and in accordance with the situational circumstances (e.g., if a building will collapse and the relief worker does not know this, orchestrators need to push this information to the relief worker regardless of whether or not the relief worker demanded this information). Finally, orchestrators must understand what information is pertinent, what is peripheral, and what is extraneous. They also must determine what agencies are the most reliable sources (e.g., based on their respective reputations), and how those agencies can provide that information, when it is needed, and in the format required.

According to the information-processing paradigm (Galbraith, 1973), each coordination mechanism needs to be endowed with a specific information-processing capability and must be matched to the information-processing demands of the environment or needs generated by the interdependence of work units. In order to deal with the characteristics of a disaster, information orchestrators need to have a range of capabilities in order to adapt and assure IQ. Moreover, one information orchestrator would not be able to coordinate all the possible information flows in a disaster management network. Several information orchestrators may be required for any given disaster situation. The exact number of information orchestrators depends on several contingencies, including the capabilities the orchestrators have. In this context, capabilities are dynamic, referring to "learned and stable patterns of collective activities through which the organization systematically generates and modifies its operating routines in pursuit of improved effectiveness" (Zollo & Winter, 2002, p. 339). The following table summarizes the necessary capabilities for an information orchestrator in PSNs.

| Table 6-2: Capabilities needed for assuring IQ and SQ | | |
|---|---|---|
| **IQ and SQ issues from field studies** | **Necessary capability** | **Type** |
| Incorrect and outdated information in agency databases | Quality auditing: the ability to conduct: information quality checks across several relief agencies and governmental agencies | Preemptive |
| SQ-trust and SQ-security, the autonomy of agencies, bridging interdependencies | Boundary spanning: the ability to integrate demand and supply across different agencies for specific information objects (need to now, have to know etc.) | Corrective |
| IQ-timelines, IQ-completeness, IQ-consistency, SQ-accessibility, SQ-response time: | Information pooling: the ability to bring information into a single, shared data space | Preemptive |
| SQ-timeliness (rapid access to knows, information that is already available somewhere is being searched for somewhere else, uncertainty) | Information library retention: the ability to retain information based on the experience from previous disasters together with some field experts | Preemptive |
| SQ-accessibility (dealing with unknowns or unprecedented information needs, accessibility, reliability and flexibly) | Service composition: the ability to accommodate new information need | Corrective |
| IQ-completeness and IQ-accuracy (e.g., in situation reports) | Enrichment: the ability to complete or complement information | Corrective |
| IQ-timeliness and SQ-response time (the next time we encounter A/or a circumstance similar to A, we will be prepared, and more likely to react adequately) | Environmental scanning: the ability to extrapolate and predict event/risk variables in order to anticipate information needs. | Exploitative |
| IQ-amount (information overload or under load), IQ-timeliness | Information categorization: the ability to define the relevancy level of information (e.g., need to know for all, police only, nice to know etc.). | Protective |
| IQ-correctness and IQ-completeness (validation of information and availability of tacit information) | Expertise consultation: the ability to Keep and maintain a list of experts on specific information classes and call upon their services when needed or errors in data or knowledge need to be identified. | Corrective |
| SQ-accessibility, SQ-response time | Reachback: the ability to access information resources that are not locally available (e.g., building structures, ship container content info). | Preemptive |
| IQ-correctness and IQ-completeness (if the quality is indicated, relief workers can decide themselves if they will act upon the information or wait for/ request updated/enriched information) | Information quality feedback: the ability to add meta-data to existing information about the source, relevancy, completeness, and timelines. The meta-data should indicate the quality level of the information. | Exploitative |

The capabilities listed in Table 6-2 allow the orchestrator to match information demand and supply adaptively and in accordance with the situation at hand. Depending on these capabilities, orchestrators can have a reactive or proactive role in the information sharing process. For instance, dealing with trusted orchestrators encourages businesses and other data owners to allow a small number of certified orchestrators restricted access to their databases (e.g., via web services). This level of reachback is far more difficult to achieve in case a larger number of relief workers have direct access to business sensitive data. In this way, stakeholders can avoid stepping into pitfalls regarding data security and privacy.

## 6.5   Synthesizing design principles

Having discussed the characteristics of netcentric information orchestration, this section moves towards the synthesis of design principles that can assure IQ and SQ during disaster response. As discussed in Chapter 3, synthesis is a creative and iterative process. The IQ and SQ issues we have encountered in the field studies (Chapter 4), followed by a critical reflection on the pathways we drew from NCO and Coordination theory (Chapter 3), lead this process. From the perspective of an information system architect, the IQ and SQ dimensions are requirements the need to satisfy. The following table provides an overview of the synthesized principles and the IQ and SQ requirements they aim to satisfy.

| Table 6-3: Design principles for assuring IQ and SQ | | |
|---|---|---|
| **Design principle** | **IQ dimension(s)** | **SQ dimension(s)** |
| 1)Maintain a single, continuously updated, information pool throughout the public safety network | Timeliness, completeness, consistency | Response time |
| 2) Enable feedback on the quality of information posts whenever possible | Correctness, completeness | - |
| 3)Maximize the reach back capabilities of the orchestrators | Completeness | Accessibility, response time |
| 4)Pre-collect and categorize information as much as possible | Timeliness, overload | Response time |
| 5)Visualize changes in crucial information categories as soon as possible | Timeliness, correctness | - |
| 6) Minimize the number of IT-interfaces relief workers need to visit for information | Consistency, Completeness, | Accessibility |
| 7) Retain as much incoming information in a digital library as possible | Completeness, | Accessibility |
| 8) Dedicate specific resources for pre-and post-environmental scanning | Completeness, relevancy | Accessibility, response time |
| 9) Re-use information | Timeliness, consistency, | Response time |
| 10) Make the source of information responsible for updating the information | Timeliness | - |

Table 6-3 provides an overview of the design principles drawn from theory and practice. In accordance with the TOGAF prescriptions for communication principles (TOGAF, 2004), we elaborate on the rationale underlying each design principle using findings from our field studies and/or theoretical foundation. We also discuss the impact these principles will have on assuring specific IQ and SQ requirements.

### Design Principle 1. Maintain a single, dynamic and network wide situation report throughout the PSN

*Rationale.* We synthesized this principle based on the NCO reachback pathway and the observation that situation reports were often outdated. The field studies in Rotterdam showed that information managers generate several different situation reports throughout the disaster response process. These situation reports acted as boundary objects between organizations carrying crucial information between multi-agency teams. However, when not generated and distributed in the right way, situation reports become a source of confusion and delay. Moreover, in the case of Delfland (Chapter 3), we found that relief workers generated consecutive situation reports from inconsistent templates, creating some confusion among relief workers. Early research by Stasser & Titus (1985) shows that pooling information permits a group decision that is more informed than the decisions of members acting individually. In particular, discussion can perform a corrective function when members individually have incomplete and biased information but collectively can piece together an unbiased picture of the relative merits of the decision alternatives. The use of a single, continuously updated information pool would also minimize the lag between outdated and up-to-date information. Accordingly, we expect that this form of synchronous information sharing will lead to improved timeliness and consistency. As decision-making groups, multi-agency disaster response teams can benefit from pooling members' information, particularly when members individually have partial and biased information but collectively can compose an unbiased characterization of the decision alternatives.

*Assured IQ and SQ requirements*: IQ-timeliness, IQ-completeness, IQ-consistency and SQ-response time

### Design Principle 2. Enable feedback on the quality of information posts whenever possible

*Rationale.* We observed several situations in which the lack of meta-information on the quality of the information shared delayed decision-making and action. Particularly, information in the situation reports provided by other teams was a source of confusion in delay in the decision-making process. Sentences such as "…there *might* be some flammable materials" or "the school may have some chemicals stored in the chemistry lab…" created some uncertainty in further actions. Since relief workers often share such information with no indication on the level of reliability, the recipients experienced difficulties in establishing further actions (e.g., act or wait for information that is more accurate). In social networks with increasing numbers of users, centralizing the tasks of approving or validating information inputs to a limited number of roles or experts will be difficult, if not impossible. Wikipedia and Google's Android Market are examples of social networks that grow with hundreds of entries by the hour. In such networks, the tasks of monitoring the quality of hundreds of entries (i.e., information, apps) are broken down in a two-

step process. First, individual information sources (relief workers or others) can give feedback in the form of quality ratings (e.g., one to five stars, score 1, 2, or 3). Based on such these ratings, dedicated experts (or orchestrators) can further validate (i.e., emphasize, enrich of remove) the entries. Accordingly, we propose that information providers should at least indicate the level of reliability of information.
*Assured IQ and SQ requirements*: IQ-correctness, IQ-completeness

### Design Principle 3. Maximize the reach back capabilities of the orchestrators

*Rationale.* We synthesized this principle from the NCO reachback pathway and the observation that relief workers have limited direct access to information sources. Each of the three field studies exhibited instances of poor reach back. This means that information managers were unable to access information directly for use in the multi-agency team. In Rotterdam for instance, access to container ship cargo information was a recurring source of delay since information managers could not access information stored in the database of the shipping agency. Instead, relief workers themselves made several information requests by calling the emergency control room, a field level relief worker or the representative of the business or private organization. Accordingly, this principle suggests that information system architects focus on maximizing the reachback capabilities of information orchestrators for a variety of scenarios and respective information needs. The assumption here is that orchestrators act as trusted third parties and are aware of the sensitivity of information.
*Assured IQ and SQ requirements:* IQ- completeness, SQ-accessibility, SQ-response time

### Design Principle 4. Pre-collect and categorize information as much as possible

*Rationale.* We have observed that relief workers often collect information objects they need after the team meetings. This means that information collection is a reactive process, after the need for information surfaces during team meetings or events in the field (e.g., explosion of a gas tank). This while there is very little time during the response phase to collect and interpret information. Recognizing that some information objects are dynamic and change in value, the majority of the information objects needed during a disaster can be pre-collected for a range of scenarios, enabling orchestrators to pre-collect and categorize these objects prior to the team meetings (instead of searching for them after each meeting). Using such libraries, orchestrators can already collect and prepare some information objects prior to the identification of their necessity. Another purpose of this form of advance structuring is to reduce the likelihood of information overload. Considering our observations of relief workers during training exercises, we argue that the changes of information overload are high when relief workers are confronted with much new and uncategorized information, for instance when (re)joining a team meeting. We expect that the upfront collection of information will not only shorten SQ response time, but also allow relief workers to find the information they need before it is too late. The categorization functionality should also allow hiding information that is not of interest at a particular time. As such, we propose that the categorization of information is important for avoiding information overload. This is in line with the observations of Turoff et al (2004). A dynamic library of 'in any

case needed information' (e.g., weather information, location coordinates) can already be in place and is useable for daily operations as well. In this way, orchestrators can collect relevant information more rapidly. In addition, this library should contain experiences from previous disasters.

*Assured IQ and SQ requirements:* IQ-timeliness, IQ-overload and SQ-response time

### Design Principle 5. Visualize changes in crucial information categories as soon as possible

*Rationale.* During disasters, information is outdated rapidly and it is important that relief workers know when a particular information object (e.g., the number of victims) has changed. The three field studies revealed that relief workers had many difficulties in determining which information is new or changed compared to what they already knew. In the Rotterdam field studies for instance, the situation reports in CEDRIC did not provide any means of indicating new information within a situation report. In Delfland, relief workers actually discussed amongst each other whether the information posted on the whiteboards was still timely. As such, we propose that changes in information should be visible as soon as possible.

*Assured IQ and SQ requirements:* IQ-timeliness, IQ-correctness

### Design Principle 6. Minimize the number of IT-interfaces relief workers need to visit for information

*Rationale.* The Gelderland field study is an example of what could happen when relief workers are required to work with several applications (web-based or thick clients) for collecting, enriching, validating, and sharing information in the PSN. Not only does the use of several applications burden computing power making the applications less responsive, they also create opportunities for information inconsistency and fragmentation when using several applications. For instance, in the Rotterdam-Rijnmond case, we also observed some difficulties for relief worker trying to run and work with several applications at the same time. A 'one-stop-shop' or single window for all information needs can improve access to timely and complete information, while assuring information system reliability by means of reduced network and computing loads. This principle enables the re-use of application functionality, something that various scholars have emphasized in the development of service-oriented architectures. Following this principle, any application used for netcentric information orchestration needs to synthesize information from a wide range of heterogeneous information sources. These include public and private databases, repositories, and digital libraries; physical sensors such as weather sensors and "social sensors" such as blogs, social networking sites, and reports from social networks of individuals who do not have direct access to the Internet; and traditional broadcast media. This principle does not suggest building monolithic information architectures, but one online access point for information orchestrators.

*Assured IQ and SQ requirements:* IQ-consistency, IQ-completeness, SQ-accessibility

### Design Principle 7. Retain as much incoming information in a digital library as possible

*Rationale.* As a disaster progresses more and more information becomes available in the PSN. In the field studies, we found that there are no means for retaining in-

formation throughout the network of agencies. The whiteboards in the HHD case do provide the capacity to post some information, however the physical size of these whiteboards acted as limits for retaining information. In the Rotterdam study, we observed that there were no directly exploitable libraries or information storage systems in which the information flowing in or out of the teams could be stored and organized for re-use. In other words, it was difficult to maintain and update team level memory. Therefore, some information resources were repeatedly acquired (i.e., location of the incident) leading to unnecessary utilization of the information manager or the control room. We do not consider the projected situation report (on the projection screen) as a library for two reasons: (1) they contained either incomplete or outdated information from other teams (i.e., strategic level) for internal decisions that are being taken at the moment supreme and (2) team members were unable to exploit knowledge gained from previous (real) disasters in the area. Based on information processing theory, Galbraith (1973) suggests that a team can be made to handle higher environmental complexity if its repertoire of information is expanded continuously and its ability to exploit such repertoire is correspondingly improved. Lee and Bui (2000) also recognized the need for such a dynamic capability and suggest that the design of any disaster response system should support some form of organizational memory component and should somehow be able to capture both tacit and explicit knowledge about how prior crisis situations were dealt with. A library of 'in any case needed information' (e.g., weather information, location coordinates) can already be in place and is useable for daily operations as well. In this way, orchestrators can collect relevant information more rapidly. In addition, this library should contain experiences from previous disasters.
*Assured IQ and SQ requirements:* IQ-completeness, SQ-accessibility

## Design Principle 8. Dedicate specific resources for pre-and post-environmental scanning

*Rationale.* We observed that the decision-making team was often blindsided during their meetings. Since the team leaders (e.g., mayor, chief commander) often prohibit mobile phone or radio communication during the team meetings, the commanders of the respective agencies were unable to attain situational updates. As a result, they were often unaware of new developments in the environment (i.e., release of asbestos) and were unable to adapt their decisions to accommodate new developments. We argue that the teams could have captured many disaster related if some of the team's resources were dedicated to scanning the environment. Environmental scanning is the internal communication of external information about issues that may potentially influence an organization's decision-making process (Albright, 2004). The idea is that through consistent monitoring of external influences, decision-making teams can shape their own internal processes to reflect necessary and effective responses. Environmental scanning includes a continuous flow of assessing the organization, adapting, developing a strategic plan and assessing again (Choo, 2000). Albright (Albright, 2004) adds that environmental scanning is not a stagnant process, it should be constant and ongoing in order to maintain a preparative stance as environmental influences arise. The process of understanding the match between external influences and internal responses assists in adjusting organizational structure and strategic plans that are designed to be more effective and flexible to changing external conditions (Choo, 2000). Sources that can be scanned include social media networks such as Twitter,

YouTube, Flickr, which have proven to contain timely information during disaster situations (Plotnick, White, & Plummer, 2009).
*Assured IQ and SQ requirements:* IQ-timeliness, IQ-relevancy, IQ-completeness, SQ-accessibility

## Design Principle 9. Re-use information as much as possible

*Rationale.* We have observed several instances of repeated information request and collection efforts during the field studies. Since there is no shared information space or library, relief workers and information managers were often not aware of information already available in the PSN. Consequently, the redundant requests for information consumed the already scarce information management capacity of the information managers and control rooms. As such, we advocate that after initial validation by orchestrators or experts, information that is available in the PSNs is re-used as much as possible. The re-use of information could also assure a higher level of IQ-consistency since the same information can be shared repeatedly. Note that the danger here is also that relief workers repeatedly share the wrong information.
*Assured IQ and SQ requirements:* timeliness, consistency, response time

## Design Principle 10. Make the source of information responsible for updating the information

*Rationale.* This principle is mainly adapted from Michael Hammer (1990) who has stressed its importance in business process reengineering. The volume of information that relief workers share during a disaster is enormous. As some of this information (for instance the availability of hospital beds) is subject to rapid change, it is important that the owner of that information update it as quickly as possible. In centralized information systems with for instance CEDRIC, the information managers are the responsible roles when it comes to updating the information stored in the system. In such systems, the idea is that information can be collected in advance in stored within the database of the system for eventual use during disaster response. However, as mentioned in Chapter 4 on the field studies, information managers and coordinators are already very busy and do not have time (and sometimes the capabilities) to update information. As such, information system architects should leave and reinforce the responsibility of updating information with the owners of that information (e.g., firms, hospitals, governmental departments, shipping companies). This principle also leaves the responsibility and cost for collecting and updating information at owners. An assumption here is that the owners update their databases for their daily business processes.
*Assured IQ and SQ requirements:* IQ-timeliness

## *6.6   Summary*

We have defined and explained our design theory on netcentric information orchestration. Key in netcentric information orchestration is that relief workers (demand) match the available information sources in the public safety network (supply) to the needed information. This means that all teams should be able to share information with all other teams, regardless their authority level or decision-making authority. As a two stage process, netcentric information orchestration requires information system architects to develop IT enabled capabilities prior to (advance structuring) and during (dynamic adjustment) disaster response. These capabilities should empower orchestrators in assuring IQ and SQ during disaster response. Returning to the research question, we set out to investigate in this chapter (*Which design principles can we synthesize from the knowledge base and empirical data for assuring IQ and SQ during multi-agency disaster response?*) this chapter presents ten design principles for assuring IQ and SQ. Even though these design principles are more empirically driven (field study data), they rest firmly on the pathways from NCO and coordination theory. Principle number nine (re-use information as much as possible) and ten (make the source of information responsible for updating the information) in particular resonate with pathways suggested in previous work.

The audiences for these principles include a range of stakeholders in the public safety domain. Firstly, the principles are meant to guide information system architects in (re)designing existing architectures towards the assurance of IQ and SQ. Architects could also employ the principles provided in this research in their current practices and systematically reflect on their practices using our IQ and SQ framework. After the interviews with architects (see chapter five), we also understood the role of policy makers one the regional (Safety Region) and state (ministerial/ Dutch Department of Interior Affairs and Kingdom Relations) level. As important funders of information systems for disaster response, this audience would benefit from the set of principles proposed in this dissertation. Another audience we did not anticipate in the beginning of this research consist of software vendors and IT consultants. Throughout our field studies and interviews, we have learned that an increasing number of software vendors (i.e., Microsoft, Google) and IT consultancy firms are trying to establish a market in PSNs. In many cases, vendors advertise software products developed for different domains and purposes (i.e., business intelligence). To date, this approach has not yet led to much success for these vendors and consultancy firms. Accordingly, software vendors and IT consultancy firms could employ the empirical foundation of this dissertation to gain more understanding of the opportunities and hurdles for supporting multi-agency information management during disaster response.

Having presented the design principles, the next step in this study was to evaluate these design principles. Accordingly, chapter seven elaborates on the technical feasibly of netcentric information orchestration by translating the proposed design principles into a prototype (DIOS).

# 7 DIOS: A prototype for netcentric information orchestration

*"If a picture is worth a thousand words, a prototype is worth a thousand pictures"*

Anonymous

## 7.1 Introduction

In the previous chapter, we spent many words on introducing and explaining principles for netcentric information orchestration. In line with the statement quoted above, this chapter presents a prototype that we used for evaluating the design principles in a gaming-simulation (Chapter 8). According to Dictionary.com, the word prototype comes from the Latin words proto, meaning original, and types, meaning form or model. In software development, a prototype is a rudimentary working model of a product or information system, usually built for demonstration purposes (Smith, 1991). Prototypes present the user with a relatively realistic view of the system as it will eventually appear (Mason & Carey, 1983). A prototype typically simulates only a few aspects of the features of the eventual program, and may be completely different from the eventual implementation. The purpose of the prototype in the present study is to embody and demonstrate the principles behind netcentric information orchestration (discussed in Chapter 6) with further (end-user evaluation by relief workers) in mind. According to Bernstein (1996), modern information system development demands the use of prototyping, because of its effectiveness in gaining understanding of the requirements, reducing the complexity of the problem and providing an early validation of the system design. Prototyping provides two key benefits: (1) it reduces uncertainty associated with realization of netcentric information orchestration, addressing the typical question to this design theory and (2) it provides a learning opportunity by getting an early feedback on the idea from students and professionals. In addition, a prototype model can demonstrate to users what is actually feasible with existing technology, and what weaknesses exist with this technology (Martin, 2003). The users can relate what they see directly to their needs. Disadvantages of prototyping include: the fostering of undue expectations on the part of the user, what the user sees may not be what the user gets, and availability of application- generator software may encourage end-user computing (Lantz, 1986).

In accordance with Ince & Hekmatpour (1987), the stages in our prototyping process consist include: (1) the establishment of prototyping objectives, (2) functionality selection, (3) prototype construction and (4) prototype evaluation. This chapter proceeds by stating our choices during these stages in chronological order. Next, we discuss two versions of the prototype that we developed, including the design choices regarding the presentation, logic and data layers. Finally, we reflect on the development of the prototype and its embodiment of the design principles stated in the previous chapter.

## 7.2    Stage 1: the establishment of prototyping objectives

In the first stage, it is important that both the developers know exactly what a prototype is aiming to achieve and the establishment of prototyping objectives is one of the first activities to be undertaken by the developers. The main objective of the prototyping stage was to develop a reliable and easy to use online application that embodied the principles behind network centric orchestration in such a way that these we could evaluate these principles using a quasi-experimental setting.

An IS prototype is an early version of a system that exhibits the essential features of the later operational system (Sprague & Carlson, 1982, p. 85). While admitting that several other definitions for prototypes also exist, the following definition is adopted since it captures our understanding and purpose: "a prototype as the first embodiment of an idea" Glegg (1981, p. 89). It is tentative and its purpose is to validate or test the idea in question. Neither the prototype's form nor the materials used in its construction have to be those of the final design, as long as the basic idea or concept can be tested (Ibid.). Typical characteristics of a prototype include: (1) functional after a minimal amount of effort, (2) a means for providing users of a proposed application with a physical representation of key parts of the system before system implementation, (3) flexible modifications require minimal effort and (4) not necessarily representative of a complete system (Martin, 2003).

Even though the difference between a prototype and a working model is clear in industrial sectors (i.e., scale models of cars), differentiation between software based prototypes and products is more difficult. Certainly in mechanical engineering, a prototype (for example, of a bridge or an aircraft) can be either a scaled-down model or a full sized version. In software engineering, however, there is no suggestion of a complete version of the system being produced since the functions will be to illustrate specific important aspects of the final system (Gray & Black, 1994). Just what aspects are to be included will vary depending on the intended function of the prototype? ISs are similar to engineering systems because they too perform transformations on (data) objects that are undergoing a change of state. The prototyping technique has a long tradition in developing engineering systems (Janson & Smith, 1985). Major differences between prototyping and the traditional systems development life cycle are the lack of tightly written systems design specifications and the short time period required to provide the user with an initial system for actual "hands-on" experience (Ibid.). The nature of a prototype: iterative (Type I) and throwaway (Type II), determines factors such as the design method and the amount of resource to be allocated to the prototyping stage (Lantz, 1986). In the iterative approach, the prototype is changed and modified according to user requirements until the prototype evolves into the final system. In the throwaway approach, the prototype serves as a model for the final system.

Throw-it-away prototyping involves the production of an early version of a software system during requirements analysis. Developers can use such a prototype as a learning medium between the developer and the end users during the process of requirements elicitation and specification. An important characteristic of this approach is that developers need to construct the prototype very rapidly. In doing so, developers often have to comprise some aspects of prototype (e.g., graphics and flexibility). What is crucial about throw it away prototyping is the process and not the product; almost invariably, the latter will be discarded when the developer and the users have converged to an adequate set of requirements. Since we needed to

develop a prototype for principle demonstration and evaluation purposes in a relatively short time, we decided to develop a throwaway prototype. The main objective

## 7.3 Stage 2: functionality selection

Considering the matrix of functionalities a prototype needs to provide, prototyping can be carried out in both a vertical or horizontal fashion (Ince & Hekmatpour, 1987). The former involves incorporating all the functions, albeit in a simplified way, in the prototype: the latter involves a selection of functions. Since our purpose with the prototype was to demonstrate the technical feasibility of the principles behind network centric orchestration and allow for quasi-experimental gaming-simulation (Chapter 8), horizontal prototyping based on a limited set of functionalities was sufficient. The prototype needed to provide two types of functionalities: principle-related and tasks-related functionalities. Table 7-1 summarizes the principle-related functionalities that the prototype should support.

### Table 7-1: Principle-related functionality selection

| Design principle | Required functionalities | Description |
|---|---|---|
| Maintain a single, continuously updated, situation report | 1) Network wide situation report template and 2) automatic refresh and update | A single situation report should be retrievable by all users whenever necessary |
| Enable feedback on the quality of information posts whenever possible | Information quality rating | Every user should be able to rate the information they share or rate the information shared by others |
| Categorize information as much as possible | Information filtering and prioritization | Users should be able to view and prioritize information based on their preferences (i.e., the time of posting, the sender or the type of info) |
| Allow changes in crucial information categories to be seen as soon as possible | Highlight information object modifications | Modifications or updates in information objects should stand out and be clearly visible |
| Retain as much incoming information in a library as possible | Library of shared information | Information should be stored in an centralized and easy to access library |
| | Date and time stamp | The prototype should generate and show an automatic date and timestamp of each information entry |
| Dedicate specific resources for environmental scanning | Access to external social networks | Users should be able to view post on several social media sites based on key words (e.g., Twitter, You-tube). |
| Re-use information as much as possible | Shared information space | Information already shared by others should be visible in a shared information space |
| Standardize information formats as much as possible | Standardized data entry and output fields | The prototype should have standardized input and output forms for each information type |
| Re-use existing application services as much as possible | Standardized message interfaces | Messages should be exchanged in standardized data formats |

Table 7-1 outlines the principle-related functionalities that the prototype would need to provide (based on the design principles listed in Chapter 6). Note that not all of the design principles are deducible in IT functionalities since some principles suggested organizational modifications to the information system architecture (i.e., orchestrator role definition). Task-related functionalities include a list of functionalities that provide relief workers with the basic information necessary for their tasks. These functionalities included access to geographical and meteorological information. Since these task-functionalities allow relief workers to progress in their activities independent of our netcentric information orchestration design, we were not planning to evaluate these in the quasi-experiments. The following table outlines the tasks-related functionalities the prototype should support.
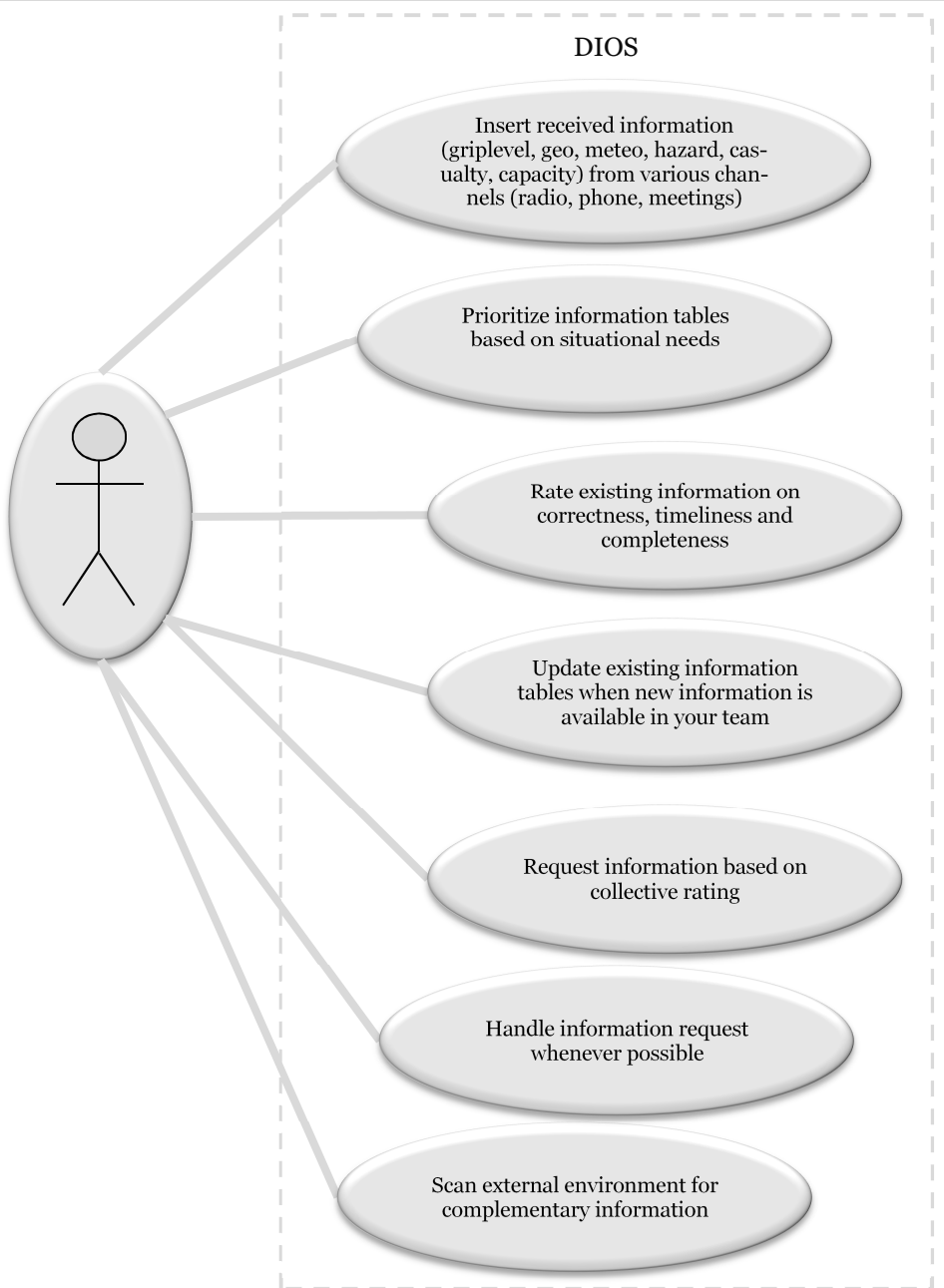
**Table 7-2: Tasks-related functionality selection**

| Tasks | Required functionality | Description |
|---|---|---|
| Log-in to the system | Role based access control | The system should allow a secure login with username and password |
| Share visual location information | Geographical information plotting | Information about the location and its area should be presented on a digital map |
| Share weather information | Meteorological information posting and retrieval | Information about the weather conditions should be post-able and retrievable |
| Share situation report | Situation report generation | Teams should be able to share situation reports |
| Request for information | Information request | The system should present a list of information requests of users so that others can fulfill these requests. |
| Share casualty information | Information posting and retrieval on casualties | Information about the casualties should be post-able and retrievable |
| Share danger-related information | Information posting and retrieval on hazards | Information about the dangers should be post-able and retrievable |

The table above lists the main tasks-related functionalities that we need in our prototype. The following sections elaborate on the use cases and scenarios based on these functionalities.

### 7.3.1 Use cases

We have chosen to develop a use case diagram, which is part of the Unified Modeling Language (UML) framework. The main reasons for choosing UML are that UML is easily extensible and easily understandable. A use case consists of several use cases. A use case is the description of a system's behavior on the users input (Alexander & Maiden, 2004). In other words, what does the system do when the user interacts with the system? As we are designing a network-centric prototype, we did not separate commanders and subordinates; every relief agent can do the same with the system. Therefore, the following use case diagram (figure 7-1) only includes one role, the role of orchestrator.

**Figure 7-1: Use case diagram for orchestrator role**

DIOS

Insert received information (griplevel, geo, meteo, hazard, casualty, capacity) from various channels (radio, phone, meetings)

Prioritize information tables based on situational needs

Rate existing information on correctness, timeliness and completeness

Update existing information tables when new information is available in your team

Request information based on collective rating

Handle information request whenever possible

Scan external environment for complementary information

As depicted in figure 7-2, the primary user in this system is the *orchestrator*. The next section presents an UML class diagram that we used for configuration the database behind DIOS. In addition, this class diagram serves as a reference model for documentation of disaster specific information objects.

### 7.3.2   Class diagram

In software engineering, class diagrams can be used for defining the structure of classes, in case an object-oriented programming paradigm is followed (Ambler, 2009). Class diagrams depict the classes, of which an object can be an instance. Within each class, we can formulate attributes and methods. Since the use case functionalities (e.g., inserting information and selecting information) discussed in the previous section is relatively straightforward, the methods and attributes of each class are roughly the same. The figure below depicts the class diagram. We use this class diagram as a template for the network situation network discussed later.



**Figure 7-2: Class diagram**

The main class in this functional design is the situational report (sitrep). A sitrep consists of several, predefined information objects, such as 'Dangers', 'Location' and 'Casualties'. This is in line with the functional requirements of 'Standardized Input' and 'Standardized Output' as mentioned in table 7.1. Furthermore, the methods in each class are only 'get and set'-methods. This is because the main functionalities of this system are information input and output. Notice that the use cases 'Login' and 'Logout' are not linked to this class diagram as several packages exists that offer a standardized way to implement this functionality.

### 7.4   *Stage 3: prototype construction and support environment*

Prototype construction involves the actual development process required to produce the prototype. Here, the type of prototype needed influences the choices for

construction methods and instruments. Since we chose to develop a throw-it-away prototype, a fast, low-cost development process was necessary. Prototyping is based on building a model of the system to be developed. The initial model should include the major program modules, the data base, screens, reports and inputs and outputs that the system will use for communicating with other, interface systems' (Lantz, 1986). We called the prototype DIOS, which is short for Disaster Information Orchestration System. The first versions of this prototype were thus an approximation to the desired software product, or some important part thereof.

Since we wanted to develop a throwaway prototype within a short time frame we chose to work with an IDE called Microsoft Visual Studio Express (see figure 7.3). We selected this environment for two reasons: (1) we had prior knowledge on programming within this environment and (2) the environment is free to use. This environment developed by Microsoft represents lightweight versions of the Microsoft Visual Studio product line. Its main function is to create ASP.NET websites. It has a WYSIWYG interface, drag-and-drop user interface designer; enhanced HTML & code editors; a (limited) database explorer; support for other web technologies (e.g., CSS, JavaScript, XML); and integrated, design-time validation for standards including XHTML 1.0/1.1 and CSS 2.1.

**Figure 7-3: Screenshot of IDE programming environment**



We constructed both versions of DIOS based on a Service Oriented Architecture (SOA). This choice allowed us to assure interoperability and flexibility (see Chapter 3). SOA addresses two of the most important design goals set forth by (Pilemalm & Hallberg, 2008), namely to (1) make it possible for crisis management teams to keep working the same way as to what they are used to and (2) allow the

use of existing resources from several agencies in a crisis situation. In order to fulfill the service re-use and interoperability required, DIOS employs *web services*. The communication between web services uses Extensible Markup Language (XML), which is a commonly used standard for encoding web applications (W3C, 2010c). The services itself are described by Web Services Description Language (WSDL). WSDL is an XML format for describing network services as a set of endpoints operating on messages containing either document-oriented or procedure-oriented information (W3C, 2010b). The information that is sent between services is encapsulated in envelopes with the use of the Simple Object Access Protocol (SOAP). SOAP is a lightweight protocol for exchange of information in a decentralized, distributed environment (W3C, 2010a). Finally, a Universal Description Discovery and Integration (UDDI) repository is used for registering all available services. UDDI is a platform-independent, XML-based registry for businesses worldwide to list themselves on the Internet (OASIS, 2010). By using XML, WSDL, SOAP and UDDI, relief agencies are able to operate autonomously while still using and integrating each other's services.

Apart from choosing interface and communication protocols for DIOS, it is also necessary to establish which programming language we would employ. The advantages of using the SOA approach and Web services is that the Web services can be written in any suitable language, like C#, Java, C, C++ or COBOL. We chose to program DIOS in C# because as this language makes it relatively easy to program web services and we had some prior experience with this language. On site disaster response teams (i.e., CoPI) have access to relatively fast notebooks and PCs that would opt for a language like C++ or a platform-independent language like JAVA. However, the usage of this language to program DIOS would decrease the flexibility of the system since the software should always be preinstalled. Therefore, there is opted for a server-sided web language like PHP and ASP. The advantage is that any computing device having access to the network will be able to use the system. Any device access to the internet by GPRS, UMTS or WIFI will be able to use these services. Table 7-3 summarizes the components of the prototype development environment.

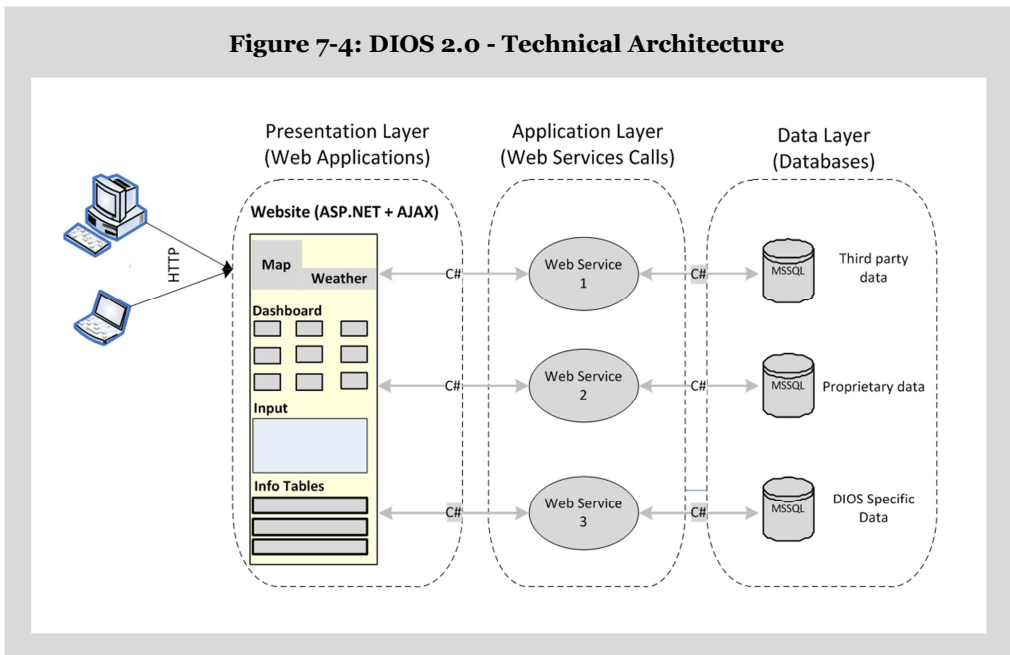| Table 7-3: Prototype development environment | | |
|---|---|---|
| **Component** | **Requirement** | **Rationale** |
| Communication Protocols | XML, WDSL, SOAP and UDDI | Because DIOS needs to be interoperable, web service protocols are used |
| Programming Language | C# | Relatively easy to program web services in C# |
| Scripting Language | ASP.NET | Runs on the same framework as C# and has built-in features for developing web services |
| Application Framework | Microsoft .NET Framework 3.5 SP1 | Provides a well-designed framework for easily implementing web services and web applications |

Next to the programming language for programming the web services, we also needed to script the website (presentation layer). Since we had already chosen to use C#, a logical alternative for the scripting language was ASP.NET. In addition,

both C# and ASP.NET are able to run on the same .NET framework provided by Microsoft. The drawback of this choice is of course a vendor lock-in effect, yet for this proof of principle, it was suitable enough. The choice for software components is based on the SQ requirements of flexibility and interoperability. While flexibility is assured through the possibility to re-use or modify services easily, interoperability is ensured because the use of web services enables heterogeneous applications to communicate with other services. Eventually, we opted for a complete Microsoft-based development environment because it was made easy to program web services using the .NET framework.

## 7.5  DIOS version 2.0

The development of DIOS 2.0 started after a pre-test with master students (see chapter 2). The development period was almost 2 months (February-March 2010). The pretest showed that the first DIOS design failed when used by several orchestrators. We revised DIOS 1.0 by adding and removing several important functionalities. The technical architecture of DIOS 1.0 also played an important role in drawing up the architecture of DIOS 2.0. This three-tier architecture was a steady basis for incrementally developing the application. In addition, after each part of the presentation layer was added, testing and debugging iterations were made in which all layers were tested on consistency and error handling. The following figure illustrates the technical architecture behind DIOS 2.0.



**Figure 7-4: DIOS 2.0 - Technical Architecture**

Considering this technical architecture, we should mention that we made several noteworthy changes in the presentation layer compared to DIOS 1.0. The most notable changes are the removal of the wiki and the introduction of a dashboard in DIOS 2.0. The functionalities between the two versions differ significantly in all layers of the application. The main differences lie in the presentation layer of

the application. Besides removing the wiki and inserting a dashboard, DIOS 2.0 consists of complete other technologies, such as AJAX. The table below shows the key differences, including why we chose to update DIOS 2.0 in such a way.

**Table 7-4: Comparing DIOS 1.0 and DIOS 2.0 - Presentation Layer**

| Feature | DIOS 1.0 | DIOS 2.0 | Rationale |
|---------|----------|----------|-----------|
| Wiki | Available | Not available | Using the wiki would take too much time to familiarize the players of the gaming-simulation |
| Logging in/out | Available | Not available | Given the strict timeframe of redesigning DIOS, the Login feature could not be implemented |
| Roles | Explicitly specified | Implicitly specified (users can indicate who they are when posting information) | There was too little time to implement roles for each player |
| Refresh Rate | Full Page Refresh each 10 seconds | Partial Page Refresh using AJAX | AJAX makes the user experience better and more intuitive |
| Wiki Search Function | Included | Excluded | No wiki was installed, therefore no search function was made |
| Use of Google Maps | Yes, in POI Web Service, but not fully operational | No, made use of a static map | For the purpose of a gaming-simulation, a static map was sufficient |
| Dashboard | Yes, but not generic | Yes, generic and for every user accessible | A dashboard can give users the latest update of the situation in one eye catch |
| Collapsible Panels | No | Yes, for information tables | Collapsible Panels can prevent information overload by not showing all available information |
| Rating information | Done with a scale (1-5) and colors (green-orange-red) | Done with 1 reliability indicator with a scale (Low-Medium-High) | Easy to implement and easy to understand for users. However, the colors and 1-5 scale could be recommended for further development. |
| External information | Implicitly visible | Explicitly visible as a Tab in the Input | The role of external information can be of significance in disasters, so an explicit notion seems important |

There are no real changes made in the application layer, except for calling the web services. In DIOS 1.0, a web service was invoked by using a "fixed link web service": a static URL that points to the web service. In DIOS 2.0, calling web services is implemented differently: by using JavaScript, a copy of the web service is created on the web server and that copy is called first. Only when that copy becomes corrupt-

ed, the real web service (the 'Fixed Link Web Service') is invoked. It makes a difference in efficiency to call web services using JavaScript because operations (like inserting and selecting data) can be implemented more quickly. Although certain aspects of DIOS 2.0 are more advanced than those of DIOS 1.0, the insights and some features of DIOS 1.0 remain important in the further development of this system. DIOS 2.0 has one main website (DIOS.aspx) which consists of 4 distinct parts:

1. *Map and Weather information:* in the first part, the map of the disaster scene can be loaded together with the current time and weather information (see figure 7-5).
2. *Dashboard:* the dashboard shows the latest information concerning relevant information for disasters including. casualties, bystanders, dangers and information requests (see figure 7-6).
3. *Input:* this part of the website gives the user the possibility to input data into the system. This is done in a structured manner where several tabs are used for several different information objects (see figure 7-7).
4. *Information Tables:* whereas the dashboard only shows the latest information available for each type of information, the information tables keep track of all information entries into the system, providing a full "information system memory" for each disaster (see figure 7-8).

The screenshots below represent each part of the presentation layer in DIOS 2.0. As the gaming-simulation took place at the Police Academy of the Netherlands, we decided to code DIOS 2.0 Dutch. Therefore, the screenshots below show the use of Dutch instead of English. The first functionalities relief workers see in DIOS 2.0 are the disaster area map services and the meteorological information service (Figure 7-5).

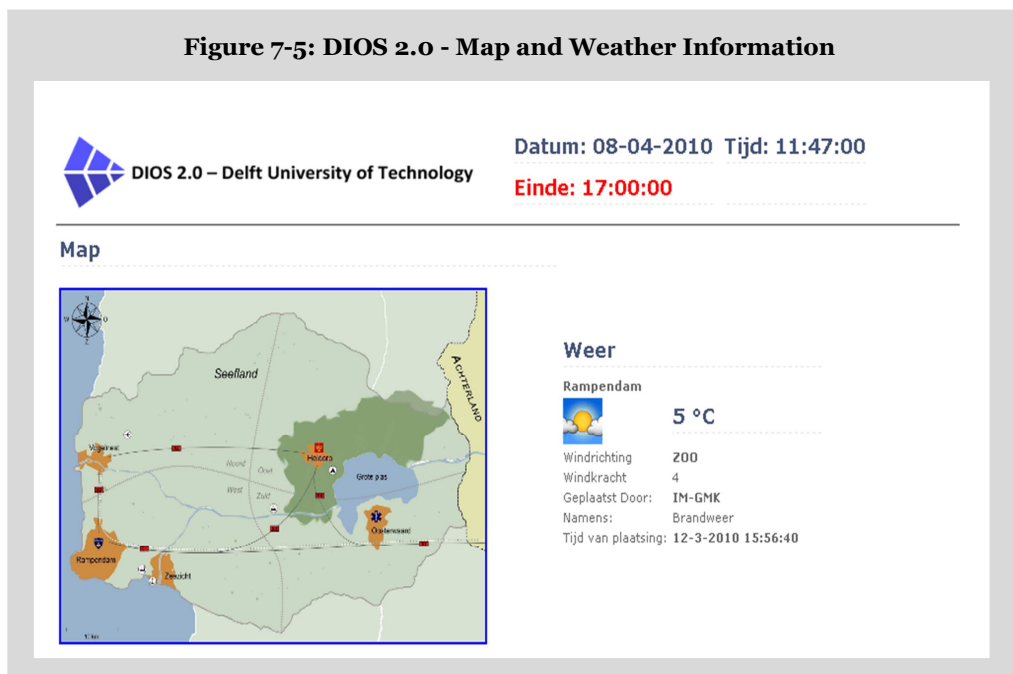**Figure 7-5: DIOS 2.0 - Map and Weather Information**

Figure 7-6 depicts the dashboard functionality in DIOS 2.0. This dashboard visualizes the most recently shared information in DIOS 2.0.

**Figure 7-6: DIOS 2.0 – Dashboard**

| GRIP | | | Slachtoffers – Lichtgewond | | | Informatie Verzoeken | | |
|---|---|---|---|---|---|---|---|---|
| | | | Creatie | 12-3-2010 16:00:42 | | Creatie | 12-3-2010 16:03:57 | |
| Creatie | 12-3-2010 16:07:18 | | Aantal | 85 | | InformatieType | Gevaren | |
| GRIP | 0 | | Locatie | Faculteit scheikunde | | Beschrijving | Maskers in veld verplicht. Methanol leidt tot irritatie van huid en slijmklieren | |
| GeplaatstDoor | IM-CoPI | | GeplaatstDoor | IM-Veld | | | | |
| | | | | | | GeplaatstDoor | IM-GMK | |

| Locatie | | | Slachtoffers – Zwaargewond | | | Capaciteit | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Creatie | 12-3-2010 16:05:37 | |
| Creatie | 12-3-2010 15:33:21 | | Creatie | 12-3-2010 16:00:59 | | Organisatie | Politie | |
| Naam | faculteit bouwkunde | | Aantal | 20 | | Type | Personeel | |
| Adres | newtonweg 5 | | Locatie | Faculteit scheikunde | | Beschrijving | agenten | |
| Woonplaats | Rampendam | | GeplaatstDoor | IM-Veld | | Aantal | 35 | |
| GeplaatstDoor | IM-CoPI | | | | | GeplaatstDoor | IM-GMK | |

| Omstanders | | | Slachtoffers – Omgekomen | | | Gevaren | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Creatie | 12-3-2010 16:03:13 | |
| Creatie | 12-3-2010 15:58:01 | | Creatie | 12-3-2010 16:04:44 | | Type | Explosie | |
| Aantal | 3 | | Aantal | 7 | | Prioriteit | Hoog | |
| Locatie | prins v oranjestraat | | Locatie | Faculteit scheikunde | | Brongebied | fac Bouwkunde | |
| InGevaar | Ja | | GeplaatstDoor | IM-Veld | | Effectgebied | | |

Scholars in the domains of strategic management (e.g., Adam & Pomerol, 2008; Clarke, 2005) have proposed the use of dashboards as instruments for both the clustering and visualization of performance indicators. A dashboard is "a visual display of the most important information needed to achieve one or more objectives, consolidated and arranged on a single screen so the information can be monitored at a glance" (Few, 2006, p. 34). Dashboards can be designed and tailored to many specific purposes depending on the task to be supported, the context of use and the frequency of use (Few, 2006).

Moreover, the various data and purposes that dashboards can be used for are worth distinguishing, as they can demand differences in visual design and functionality. The factor that relates most directly to a dashboard's visual design involves the role it plays, whether strategic, tactical, or operational. The design characteristics of the dashboard can be tailored to effectively support the needs of each of these roles. In line with Morrissey (2007), our process of tailoring dashboard content consisted of three phases: (1) identifying the main stakeholders; (2) identifying goals and establishing baseline capability for each stakeholder; and (3) selecting strategic, tactical, or operational dashboard content aligned with these goals.

Figure 7-7 depicts the information sharing functionality in DIOS. Using the information sharing functionality, orchestrators can share different types of information and indicate the level of reliability of the information shared.

**Figure 7-7: DIOS 2.0 - Information input functionality**
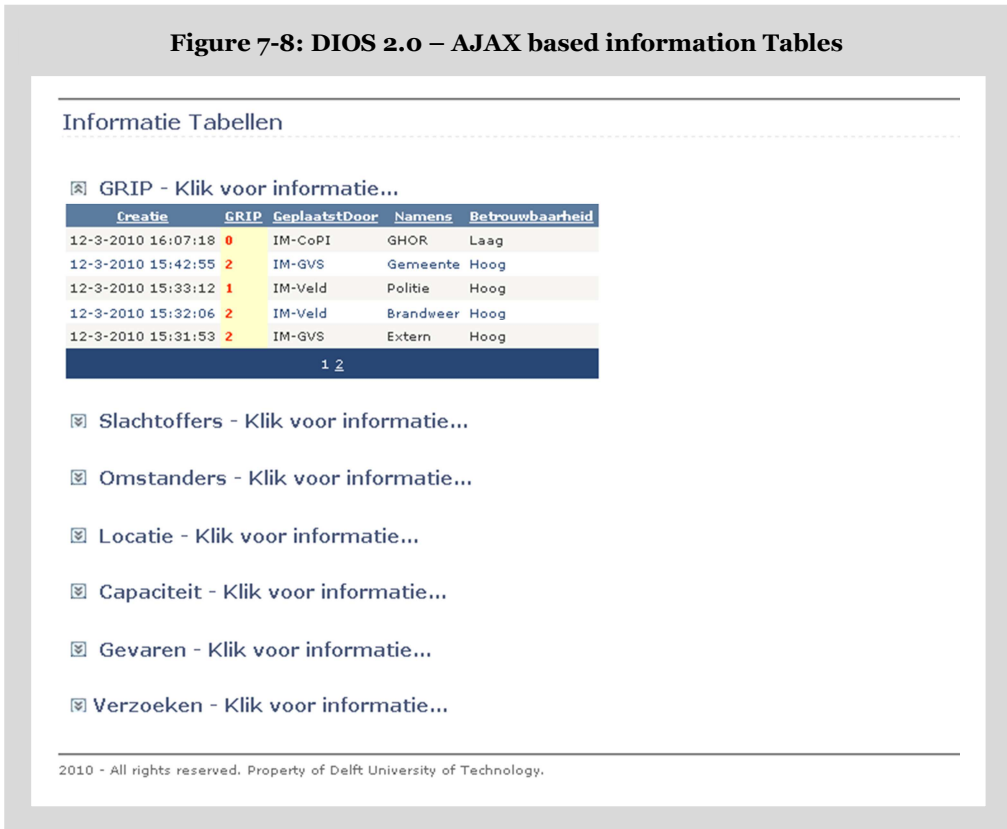


Note that none of the fields in the information-sharing table is mandatory since we wanted to prevent system failures. Figure 7-8 illustrates the various tables containing the information shared. In addition to changes in the structure of the website in DIOS 1.0, an additional technology set was used in DIOS 2.0 to automatically refresh the information tables and the dashboard. This technology set is called AJAX and stands for *Asynchronous JavaScript and XML*. AJAX is actually a set of several technologies that can be used in enriching web applications (Garrett, 2005).

AJAX is also a key component of Web 2.0 applications such as Flickr, now part of Yahoo!, 37signals' applications basecamp and backpack, as well as other Google applications such as Gmail and Orkut (O'Reilly, 2007). AJAX technology allows a web application to be more interactive by enabling *partial-page updates*, which means that parts of a webpage can be updated without having to refresh the whole page, which is usually done by pressing the F5 button. This enhancement gives the user a much richer experience with web applications (Garrett, 2005). A well-known example of web pages that use AJAX is Google.com: each time you type in a search question, Google comes up with suggestions of what the search question might be. DIOS 2.0 uses AJAX technology to enable real-time updates for the Dashboard and Information tables of this prototype.

**Figure 7-8: DIOS 2.0 − AJAX based information Tables**



Furthermore, AJAX also allowed DIOS 2.0 to hide information tables and prevent information overload for the user. In addition, AJAX allows for near real time web services invocation by using direct JavaScript calls instead of using the SOAP protocol. The application layer of DIOS 2.0 also consists of several web services that can be used for modifying, inserting or selecting data. Table 7-5 provides an overview of the web services used in DIOS 2.0. These web services are similar to set of web services employed in DIOS 1.0.

**Table 7-5: DIOS 2.0 - Web Service Definitions**

| Web Service | Explanation | Web Service Methods |
|---|---|---|
| GRIP_WS | Inserting and Showing GRIP values (GRIP is an indication used in the Netherlands that tells how severe a disaster is) | InsertGRIP() ShowGRIP() |
| Casualties_WS | Information provision and entry concerning casualties (Deceased, Heavily Wounded, Lightly Wounded) | InsertCasualty() ShowDeceased() ShowHeavilyWounded() ShowLightlyWounded() |
| InformationReq_WS | Users can post an information request when they need information on something | InsertInfoRequest() ShowInfoRequests() |
| Location_WS | Insert and Show updates of a Location (usually the disaster scene) | InsertLocation() ShowLocations() |
| Capacity_WS | This web service is used for inserting and showing the capacity, expressed in vehicles or officers, of each relief agency | InsertCapacity() ShowCapacity() |
| Bystanders_WS | Information concerning bystanders who are at the disaster scene | InsertBystanders() ShowBystanders() |
| Dangers_WS | Users can post and see information concerning several dangers on the disaster scene, such as a collapsing danger, a toxic danger or an explosion danger | InsertDanger() ShowDangers() |
| Weather_WS | Weather information can be assessed and modified using this web service | InsertWeather() ShowWeather() |

In DIOS 2.0, the data layer consists of a Microsoft SQL Server, which operates separately next to the web server. The SQL Server contained 1 database with all specific data of DIOS. There was no use of third-party data during the "Master of Disaster" gaming-simulation, as it was too risky to depend on relatively unknown service providers during the simulation. Yet, the use of third-party data in DIOS 2.0 was also easily possible due to the use of web services in the application layer. However, in the gaming-simulation, we simulated third-party data by saving this data locally in the MS SQL Server Database (the tables are HazardousMaterials and ShelterLocations). MS SQL Server 2008 Express Edition was chosen as the database management system for DIOS 2.0 because it is free to use, easy to install and extremely easy to integrate with web services written in C#. The Integrated Development Environment (IDE) used in DIOS 2.0 was Microsoft Visual Web Developer 2008, which ships with a free edition of MS SQL Server 2008. This IDE made it easier to use a MS SQL database in combination with web services because of the pre-defined classes for retrieving and inserting data. The database diagram below shows which database tables we drafted and which elements we used to make up each table.
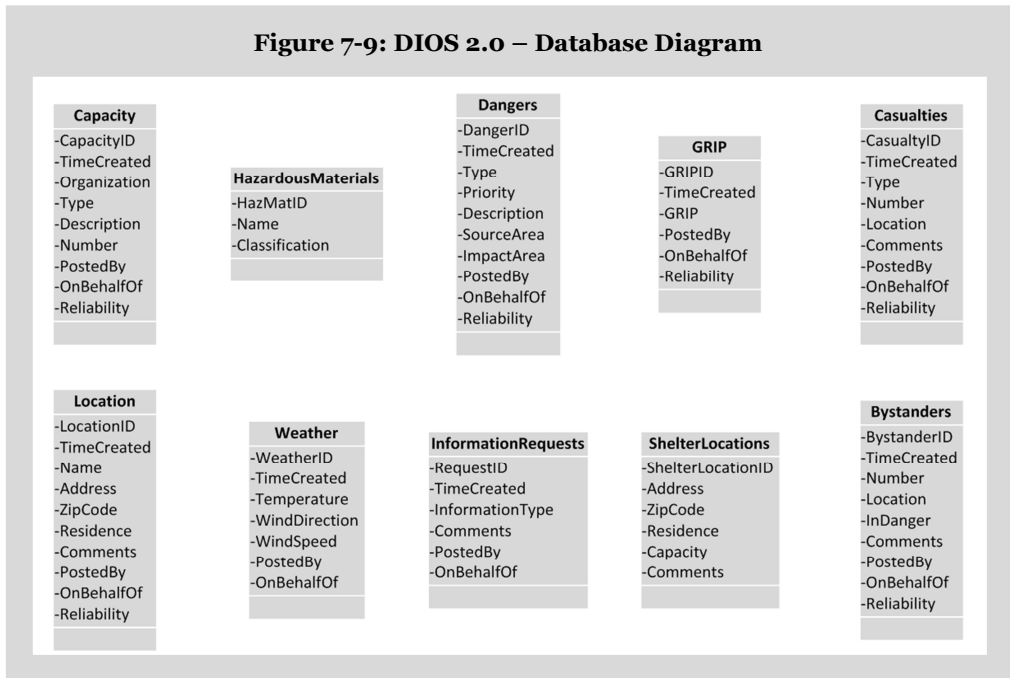
**Figure 7-9: DIOS 2.0 – Database Diagram**

Figure 7-9 illustrates the ten data tables used in DIOS 2.0. Compared to the data tables in version 1.0, the main change in the data layer is the use of a different database. The table below shows the changes made in DIOS 2.0 compared to 1.0 on the data layer level.

| Feature | DIOS 1.0 (MS Access) | DIOS 2.0 (MS SQL Server) | Design choice |
|---|---|---|---|
| | **Table 7-6: Comparing DIOS 1.0 and 2.0 - Data Layer** | | |
| Capacity | Maximum of 1 GB without real read/write problems | Maximum of 8 GB without real read/write problems | With respect to possible real implementation, an SQL database is more reliable |
| Security | Can be put on USB/CD No authentication measures | -2 Authentication measures (on the server and through the web services) -Automatic encryption of the database -Can only be used by the designated MS SQL Server | As relief workers can have sensitive information, also during disasters, security of data is can be assured |
| Implementation | Using MS JET DB and SQL queries | Using ADO DB and SQL queries | ADO DB provides for a more easy implementation when it comes to linking web services to a database |

The migration from MS Office Access to MS SQL Server was a relatively easy process. Since both database management systems use the same query language (SQL - Structured Query Language), only changing the engine (JET DB to ADO DB) was difficult. Yet, an easy transition took place where no genuine problems occurred.

## 7.6 Stage 4: Prototype evaluation

Prototype evaluation is probably the most important step in the prototyping process and one for which there is little knowledge. Users of a prototype require proper instructions prior to its use. It is important that the prototype becomes a learning medium for both the developer and the customer and the latter should have confidence that the time-consuming activities involved are actually converging to a stable set of requirements. Normally the evaluation process takes a number of cycles until this happens and requires timely feedback for productive learning.

We organized two user tests (other than the development team) for evaluating the DIOS versions. First, we evaluated DIOS with a number of master students from Delft University of Technology on February 16th 2010. As part of their regular course load, we requested master students to participate in a gaming-simulation experiment, which also functioned as the pre-test for the gaming-simulation with professionals (see Chapter 8 for more details). During this pre-test, it appeared that DIOS 1.0 had crashed on the web server just after we started with the second round of the gaming-simulation. This was of course unfortunate; however, this pre-test did reveal the main shortcomings of our prototype. After the prototype failure, we started developing DIOS 2.0.

We tested DIOS 2.0 using a team of eight PhD students and four master students using computers within and outside of the university network. We asked the twelve testers to work simultaneously with DIOS 2.0 as intensively as possible, so a thorough error handling could be done subsequently. The duration of the test was 30 minutes. The result of the test was positive; DIOS 2.0 did not crash and was still functioning afterwards. Still, there were some improvements made to DIOS 2.0 including:

1. *Error handling for special characters:* characters like question marks, brackets and exclamation marks were entered during the test session and this resulted in errors. After the test, a small character handler was built so that no errors were generated
2. *Error handling for script attacks:* two testers also entered a short HTML script in DIOS, resulting in several errors. The information fields were re-programmed afterwards, so that HTML and JavaScript scripts could not generate errors in DIOS

The pre-test has shown that testing an information system application is an extremely important step in the development process. Error handling and user friendliness of a system contribute greatly to the usefulness of the prototype.

## *7.7*   *Summary*

This chapter reports on the technical feasibility for netcentric information orchestration. Based on the principles proposed in Chapter 6, we constructed a prototype for netcentric information orchestration. The prototype allows all available data on the situation, decisions, progress and results of each stage of the response phase to be concentrated in a central information space in real time. In addition, the prototype allows the available information to be processed as quickly as possible to a dynamic overview of the incident, the impact and progress of the response efforts that is continuously updated and continuously accessible to authorized relief workers.

The first version of the prototype, DIOS 1.0 failed during a pre-test with master students. This prompted us to construct the second version of the prototype, DIOS 2.0. DIOS 1.0 had a number of technology-enabled features not found in version 2.0, such as logging in and out, a personalization of the functionalities visible to each role and partial implementation of Google Maps. Furthermore, because of the full-page refreshing feature of DIOS 1.0, we could not say that DIOS 1.0 was a full netcentric application, because after every 30 seconds users had to wait two seconds until information this application unfroze the user interface. In a time-critical situation such as a disaster response, every second counts, so because of the full-page refreshing trait and the database failure during the pretest with master students, we decided to further develop DIOS and make version 2.0. Consequently, the main difference between DIOS 1.0 and 2.0 is that refreshing (presenting updated information fields) occurs seamlessly by using AJAX technology. The user does not see a whole page refresh, only parts of the page (e.g. one table) are refreshed immediately when an update is posted. In addition, we decided that every user sees the same screen as everyone else, thereby removing the personalization feature of DIOS 1.0.

We chose to employ a single network wide situation report for shared situational awareness, where everyone has immediate access to the same information. Eventually it became clear that several trade-offs had to be made between a number of requirements (e.g. personalization vs. shared situational awareness) in order to have a stable netcentric information orchestration prototype. In the end, we preferred a stable and dependable prototype to a prototype that contains all of the functionalities possible. This because the prototype was just a tool (and not a goal) embodying the design principles to be evaluated with professionals. We discuss this evaluation in the next chapter.

# 8    Evaluation: A quasi-experimental gaming-simulation

*"Tell me and I'll forget;* show me *and I may remember;* involve me *and I'll under-stand."*

Confucius 551–479 BC

## 8.1    Introduction

This chapter reports on the results of the gaming-simulation with professional re-lief workers. We quoted Confucius in our invitation to professionals, asking them to participate in our quasi-experimental gaming-simulation. In return, the gaming-simulation provided participants with a flavor of what network-based information management approaches look like in practice and what the effects would be for in-ter-agency (horizontal) and inter-echelon (vertical) information management. The main objective of this session with professionals was to evaluate the extent to which the principles of netcentric information orchestration could better assure infor-mation quality (IQ and SQ) than hierarchy-based information systems for disaster response.

Accordingly, the gaming-simulation was the main research methodology for investigating the final research question in this dissertation, which asked, *to what extent do the proposed design principles assure higher levels of IQ and SQ for re-lief workers when compared to information systems in practice?* We started by first simulating disaster response based on a hierarchical information management architecture (round one of the gaming-simulation). Afterwards, we simulated dis-aster response based on a netcentric information orchestration architecture (round two of the gaming-simulation). The gaming-simulation was called "Master of Dis-aster" and was pre-tested with master students at the Delft University of Technolo-gy. Chapter 2 has already provided a detailed description of gaming-simulation as a research methodology. Considering chapter 2 as a prelude, this chapter proceeds by presenting the results gained from applying this methodology.
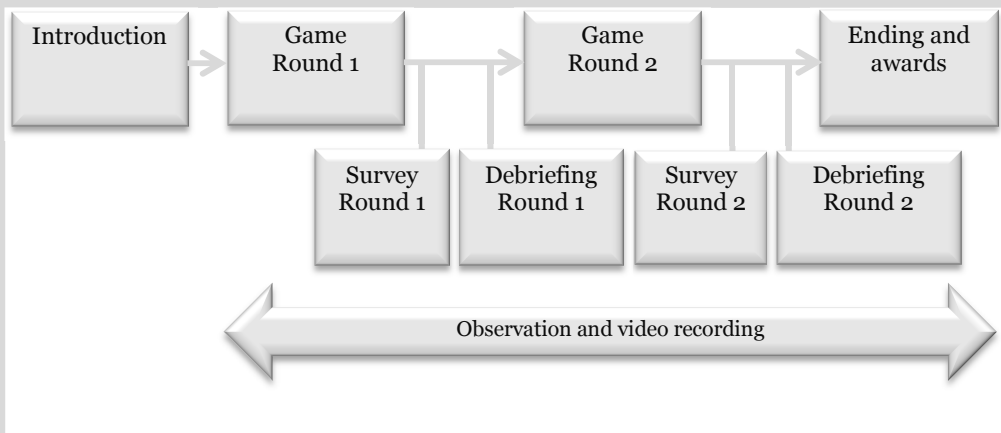
## 8.2    Situational setting

The situational setting includes all variables that surround the gaming-simulation session, but are not part of the design (Meijer, 2009). One can think of the venue, the participants and the space in which the gaming-simulation is hosted. We conducted two gaming-simulation sessions: session 1 (pre-test with master stu-dents) and the sessions 2 with professionals. The professionals were participating as part of their training at the Police Academy and they had some experience with disaster response (see section 8.5). Table 8-1 outlines the situational setting for both gaming-simulation sessions. Note that the pre-test with master students was shorter than the game with professionals. The reason for this is that we were re-stricted to a two-hour class with the students. As a result, the two debriefing ses-sions with the students were shorter than with the professionals

| Variable | Pre-test with students | Game with professionals |
|---|---|---|
| Date | Tuesday 16 February 2010 | Friday 12 March 2010 |
| Duration | 13:30-15:30 | 13:30 – 16:30 |
| Location | Faculty TPM, Delft University of Technology, Delft, The Netherlands | Gaming Suite, Police Academy, Ossendrecht, The Netherlands |
| Participants | 26 Master students | 24 Policy Academy Students |
| Motivation for participants | Mandatory part of their course hours | Demonstration of a Netcentric orchestration system, gain understanding in netcentricity |

**Table 8-1: Situational Setting**

Figure 8-1 below outlines the subsequent phases in the Master of Disaster Game.



**Figure 8-1: Overview of phases in the Master of Disaster Game**

Both the pre-test with master students and the session with professionals consisted of eight sequential phases. We briefly discuss each phase in the following subsections.

**Introduction** (15 minutes)
During the introduction, the facilitators informed the participants about the objectives of the gaming-simulation, the activities, rules and constraints. Participants could find their role description in the participant manual, a booklet that we had already distributed amongst the participants before the gaming-simulation. These manuals contained role-specific information for each participant. For the pre-test, we randomly assigned students to each role. For the gaming-simulation with professionals, we matched the roles in the game with the functions of the participants in accordance to their daily practices. The participant manual also consisted of information about the simulated safety region (see section 8.3). The introduction ended with a short movie clip that introduced the disaster situation with video and

audio. After the short film, we requested the participants to take their seat and start with the task assigned to their role.

**Round 1: Disaster response with hierarchical information coordination** (45 minutes)

The gaming-simulation started with recreating a disaster situation and it was up to the participants to manage this disaster effectively and efficiently. The main goal of the first round was to simulate hierarchical information coordination and to evaluate the effects on IQ and SQ. Similar to practice, participants were required to minimize the number of casualties and physical damage as a result of the disaster. In order to do so, participants needed to collect and share information for instance about the situation on the field, the hazards and the resources they have available. Each disaster response team had an information manager. In round one, the information managers were able to use Microsoft Word for generating situational reports during the team meetings. They also could mail these situational reports to the other teams, similar to what we observed in the Rotterdam and HHD field studies. In line with the hierarchical information coordination architecture, information sharing would take place at two levels: (1) in the multi-agency team (inter-agency), (2) within the echelons of the respective relief agencies (intra-agency information flows between strategic, tactical, and field echelon). Here, participants used situation reports and information request forms to share information between teams.

**Survey round 1** (10 minutes)

After round 1, participants were requested to fill in a short paper survey on their experiences regarding IQ and SQ during the first round. As such, the survey included questions on several IQ and SQ dimensions, the use of situation reports and the role of the information orchestrators. The survey for round 1 was included in the participant manual.

**Debriefing session 1** (5 minutes in the pre-test, 30 minutes in the game with professionals)

In the first debriefing session, the participants were requested to comment on the information management activities during round 1 and state any IQ and SQ related issues they noticed. Two facilitators moderated this session. The participants were encouraged to take notes and state comments in their participant manual.

**Round 2: Disaster response with DIOS** (45 minutes)

In round 2, we introduced a slightly different game scenario to the participants. In this round, each team had one role who could orchestrate information horizontally (between agencies) and vertically (between echelons) using the DIOS prototype (see Chapter 7). We allowed the information managers in each team to use DIOS for information management. In line with the netcentric information orchestration architecture discussed in chapter 6, information management would take place on three levels: (1) in the multi-agency team (inter-agency), (2) within the echelons of the respective relief agencies (strategic, tactical, and field echelon) and (3) within the entire public safety network, including the emergency control rooms using the DIOS prototype.

**Survey round 2** (10 minutes)
Subsequent to round 2, the participants were requested to fill in a second survey on their experience with DIOS. This survey contained the same questions on IQ and SQ as the survey in round 1 and had some additional questions on the DIOS prototype and the role of the orchestrators. The survey for round 2 was also included in the participant manual.

**Debriefing session 2** (5 minutes in the pre-test, 30 minutes with professionals)
In the second debriefing session, we again requested the participants to comment on the information management activities during round two and state any IQ and SQ related issues they noticed. Two facilitators moderated this session. The participants were encouraged to take notes and state comments in their manual.
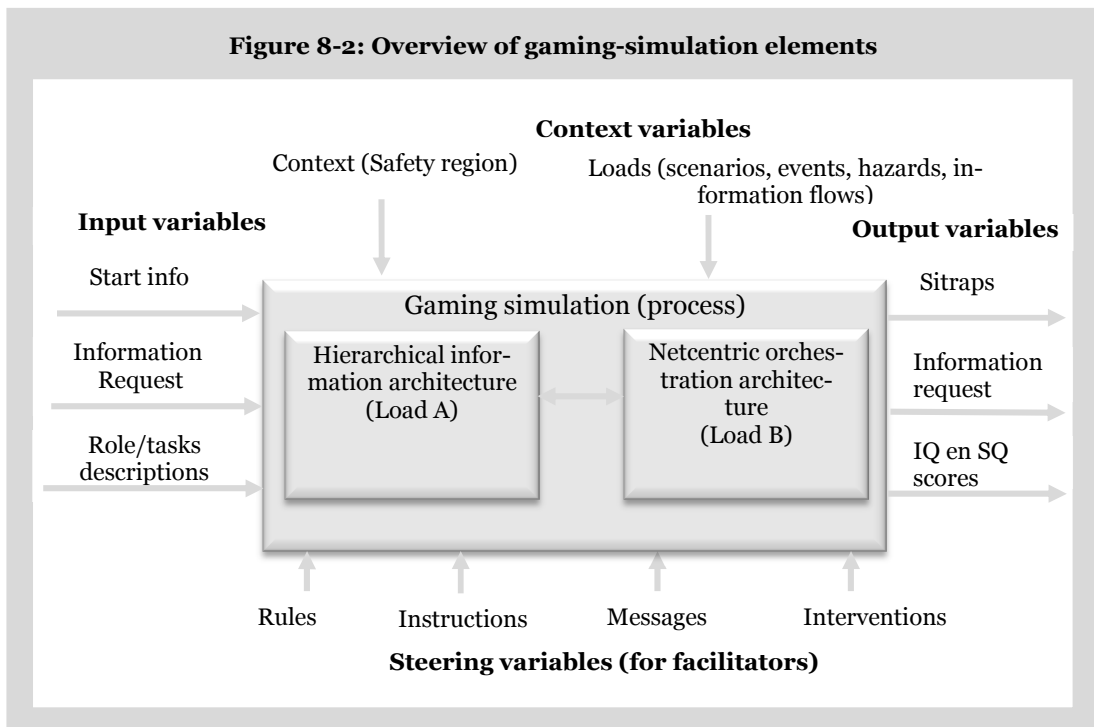
**Ending and awards** (5 minutes)
At the end of the debriefing session, the facilitators thanked the participants for their cooperation and a small present (chocolate bar) was awarded to the most active and outstanding participant in each team. We requested the participants to return their participant manual since it included their notes and response to the surveys. This chapter proceeds by discussing the scenarios, inputs and outputs of the game, followed by the means for collecting data.

## 8.3   *Master of disaster game*

Using gaming-simulation as a research method requires careful upfront planning of four types of variables: input, context, output and steering variables. The following diagram provides an overview of the main elements of the gaming-simulation.



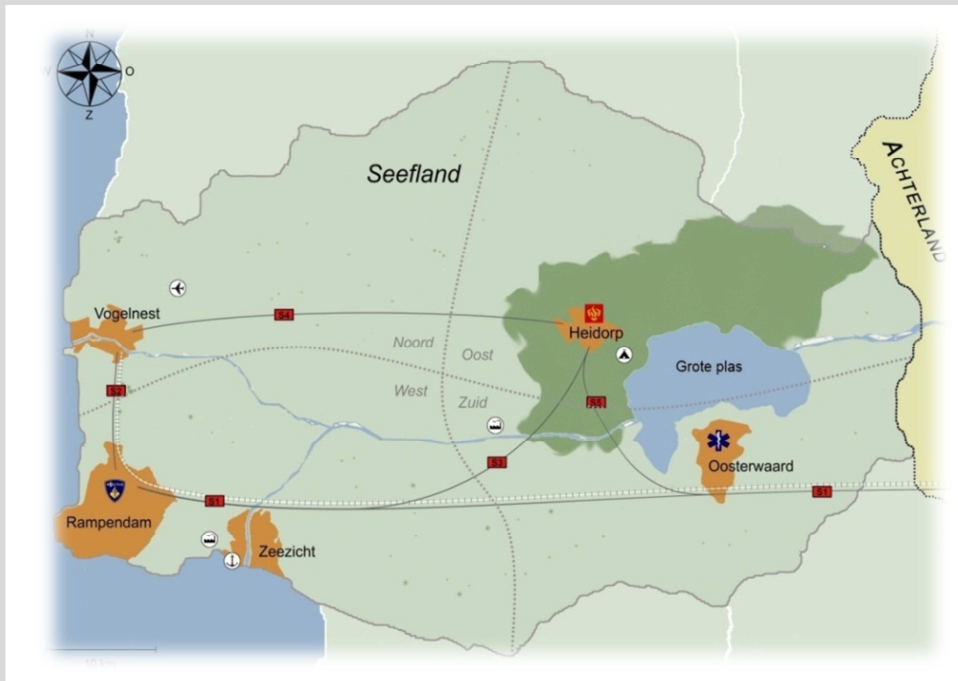**Figure 8-2: Overview of gaming-simulation elements**

The diagram depicted in Figure 8.2 outlines the various elements of the gaming-simulation, including the context, input, steering and output variables. The two experiments are depicted at the center of the diagram. The remainder of this section elaborates on each of the elements.

### 8.3.1    Context of the game

The disaster situations we simulated in round 1 and 2 occurred in the fictional safety region called "Seefland". Officially, the Netherlands is divided in 25 safety regions. Safety regions are governmental organizations, responsible for disaster preparation and response. In such organizations, the regional police, fire department and ambulance services work together to effectively prevent and repress a disaster. Safety regions usually consist of three to eight municipalities in a region. Figure 8.3 shows a map of the fictitious safety region Seefland.

**Figure 8-3: Map of Seefland**



As depicted in Figure 8-3, we divided Safety Region Seefland in four municipalities, including the city of Rampendam. This map was also included in the participant manual alongside other information on the safety region, including size, number of inhabitants and risks objects such as an airport and a seaport. We chose to develop our own fictitious safety region, instead of an existing safety region, for the following reasons:

1.   Participants of the gaming-simulation are professionals working in different safety regions in the Netherlands. Hence, using an existing safety re-

gion might benefit some of the participants familiar with that safety region. Using a fictitious safety region unknown to all guarantees the same level of context or load information throughout all the participants.

2. When using an existing safety region, some participants that work in this existing safety region might feel represented and others working in a different safety region may not feel represented.
3. A fictitious safety region allows the designers of the gaming-simulation to control load conditions for experimental purposes. For instance, we can simulate a hospital and a university in the same safety region without any discussion on whether this is realistic or not.

The next subsection discusses the actors and roles in the gaming-simulation.

### 8.3.2 Actors and roles

The roles in a gaming-simulation can be divided into roles for participants and roles for game facilitators (Meijer, 2009). In accordance with the roles observed in the field studies, we divided the roles for participants into 4 multi-agency teams with each team having a specific priority in this gaming-simulation.

**Table 8-2: Master of Disaster Game – Roles**

| Team | Roles | Explanation |
|---|---|---|
| Emergency Control Room (ECR) | 1. ECC – Police (2x)<br>2. ECC – Paramedics (2x)<br>3. ECC – Fire Department (2x) | The ECC is the first point of contact for reporting a disaster. They need to coordinate information requests from relief agencies. |
| Commando Place Incident (CoPI) | 1. CoPI – Chairman<br>2. CoPI – Information Manager<br>3. CoPI – Police Commander<br>4. CoPI – Paramedics Commander<br>5. CoPI – Fire Commander<br>6. CoPI – Local Representative | The CoPI is responsible for the efficient coordination of the field workers on a tactical level so that the disaster can be repressed accordingly |
| Municipal Crisis Center (GVS) | 1. ROT – Mayor<br>2. ROT – Information Manager<br>3. ROT – Police Commander<br>4. ROT – Paramedics Commander<br>5. ROT – Fire Commander<br>6. ROT – Municipal Crisis Manager | The ROT is responsible for efficient coordination of relief workers on a strategic and responsible for informing the press. |
| Field Workers (Field) | 1. Field – Police Officers (2x)<br>2. Field – Paramedics (2x)<br>3. Field – Fire Fighters (2x) | The field units need to share information with their commanders so that the disaster can be repressed as much as possible. |

Table 8.2 outlines 18 roles. Note that some of the roles indicated with (2x) were fulfilled by two relief workers, bringing the total of players to 24. The handbook we made available to each person prior to the game provided the role description for each participant.

In contrast with common gaming-simulations, the participants are initially not motivated to "win" or to finish first place as this gaming-simulation was not intended for that purpose. "Master of Disaster" wanted to mimic the information

management processes in a disaster setting and wants to experiment with a new type of information management system. As motivation, we announced prior to the gaming-simulation that the best player of each team would be awarded with a small prize, based on the judgment of the observers. Therefore, participants still had an incentive to do their best. The objective of each participant is framed as: *'complete a situational report (Sitrep) with the highest information quality possible'*. In order to achieve this objective, participants had to engage in the processes of information management including the following: information collection (within your team and between teams), information validation, enrichment, and information sharing (when requested by others). Next to the roles of the participants, facilitators also had to fulfill some roles during the gaming-simulation. The following table outlines these roles.

**Table 8-3: Roles for facilitators**

| Roles | Tasks |
|---|---|
| Mailman | The mailman will deliver messages between several roles in round 1. This is part of the representation of an information management system where communication is going by mail. |
| Message coordinator | The message coordinator times the progress of the game and distributes predefined messages to the various teams (via the mailman). |
| Journalist | The journalist wants to bring the news for their corporation as quickly as possible. For this purpose, he/she wants to gain as much relevant information on the disaster as possible. |
| Observers (6x) | The main task of the six observers was to observe the participants as good as possible with help of an observation protocol. The observers also were briefed before the game in answering some basic questions that might arise during the game. |

As outlined in table 8.3, nine persons helped in facilitating the gaming-simulation. The facilitators included university staff, PhD students, graduate students, and undergraduate students. Someone who had some experience in the field of journalism fulfilled the role of journalist.

### 8.3.3 Choreography

The roles and teams in the gaming-simulation were physically configured in such as way that they were familiar to the participants and in accordance with our field study findings (see chapter 4). The chorography of both rounds was quite similar, except for the use of beamers that displayed the DIOS screens. The following figure depicts the choreography of round two in more detail.
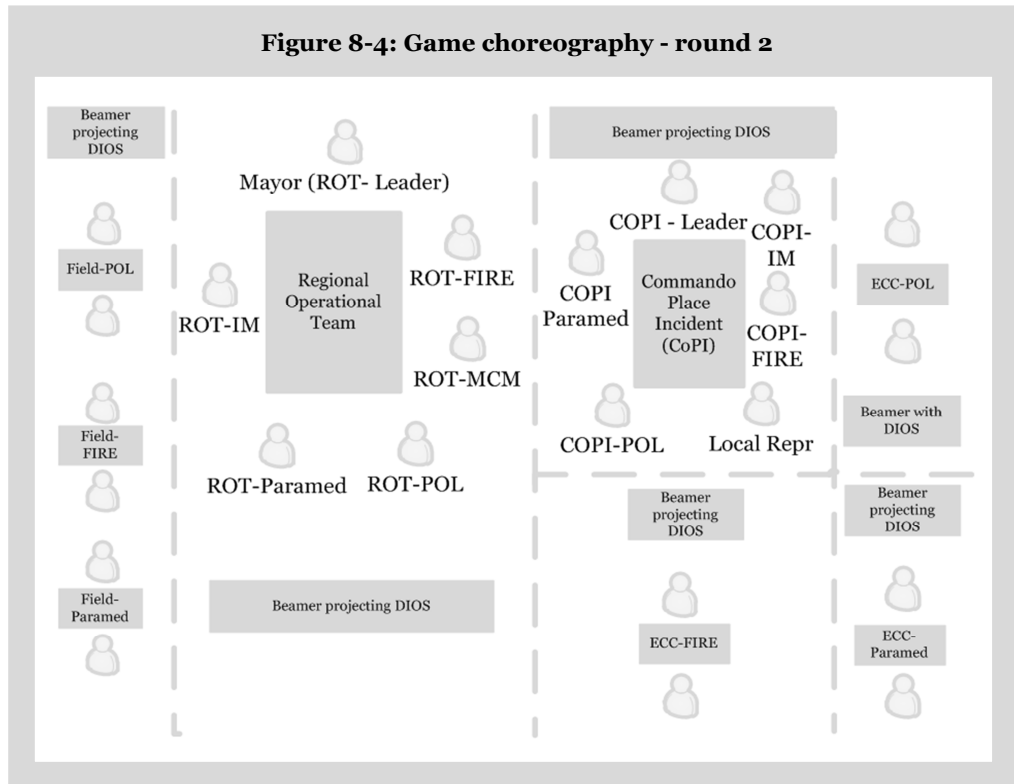
**Figure 8-4: Game choreography - round 2**

Figure 8.4 depicts the choreography of the relief workers participating in the quasi-experimental gaming-simulation. We spread the eight teams in six different rooms. Walls separated each room. The major difference between round one and round two was that there were no beamers visualizing the DIOS user interface in round 1. We discuss some rules and constraints communicated to the players in the next subsection.

### 8.3.4 Rules and constraints

Rules in a gaming-simulation can limit the behavior of participants in order to control the environment. Also, rules shape the behavior as they define what is allowed or forbidden (Meijer, 2009). Moreover, rules are necessary in order to replicate the conditions of a real disaster as much as possible and safeguard the quasi-experimental nature of the gaming-simulation. Accordingly, we established some general rules and constraints prior to the gaming-simulation. The role descriptions of the participants include role specific rules and constraints. Some general rules for all the participants in the Master of Disaster Game included:

- All communication between teams should be done using Sitrep forms, information request-response forms (in round 1) or the DIOS system (in round 2)

- Forms should be put in mailboxes (outbox). The outgoing forms will be delivered by the mailman (only in round 1)
- Everyone is expected to play the same role in the second round. This can of course lead to a learning effect amongst the participants. However, due to time constraints and a slightly different scenario it is more efficient for the participants to play the same role in both rounds
- Participants have to write only in capital letters on each form (for assuring readability)
- Participants are not allowed to walk to other rooms and teams and communicate with them
- Participants need to turn off their mobile phones in order not to disrupt the meetings (similar to what we observed in the field studies)

Next to these general rules, constraints are those design elements that limit the range of actions possible in a gaming-simulation. In contrast to rules, which define what is allowed or forbidden; constraints shape the minimum/maximum value of time, punishments, points and other variables (Meijer, 2009). The constraints of the Master of Disaster Game sessions included three major constraints.

- A meeting in the CoPI and ROT can have a maximal duration of 15 minutes
- The number of participants is limited to 25
- The time of the gaming-simulation in total cannot exceed 4 hours

The rules and constraints were stated in our opening presentation and were also repeated in the participant manuals. Having stated these rules and constraints, the next sub-section elaborates on the loads we developed for both rounds.

### 8.3.5   Experimental loads and scenarios

Experimental loads can be defined as the values of all variables in the design of the gaming-simulation (Meijer, 2009). A load also includes a scenario and script. In the paragraphs below, two experimental loads are discussed: Load A (for round 1) and Load B (for round 2). For both loads, a fictional setting is designed set in the safety region Seefland. In this safety region, we chose the city of Rampendam as the location where the disasters will take place. For comparability purposes, both scenarios took place in the city of Rampendam. However, there were some differences between the two loads regarding the contents of each disaster. In the following subsections, both loads and their contents are discussed in more detail.

#### 8.3.5.1   *Experiment A: Fire outbreak in a warehouse complex*

Experiment A is about a fire at a warehouse complex in Rampendam. This warehouse complex includes two do-it-yourself stores situated: Gamma and Leen-Bakker. These shops have explosive and toxic material in their warehouses, which can lead to disastrous consequences for the environment surrounding Rampendam. In this load, participants have to work without DIOS as an information man-

agement system. Communication between teams is done with the use of forms and a mailman.

All participants already received their start information (startSitrep) in the participant manual. The Emergency Control Room employees receive the following message:

- 13:41:22 – 12-03-2010 – 87 **FIRE - PRIORITY 1** – 3122 – FIRE BUSINESS COMPLEX
- 13:41:29 – 12-03-2010 – 87 **AMBU - PRIORITY 1** – 3122 - FIRE BUSINESS COMPLEX
- 13:41:45 – 12-03-2010 – 87 **POLI - PRIORITY 1** – 3122 - FIRE BUSINESS COMPLEX

### 8.3.5.2   *Experiment B: Fire on a university campus*

Experiment B includes a scenario in which the architecture faculty of the University of Rampendam is on fire. The great danger of this fire is that it borders on the chemistry lab of the Faculty of Chemistry. In this lab, there are many poisonous and explosive materials stored. There is also a collapsing danger of the Faculty of Architecture. In this load, participants have to work with DIOS as an information management system. All participants already received their start information and the ECC operators receive the following message:

- 15:41:22 – 12-03-2010 – 87 **FIRE - PRIORITY 1** – 3122 – FIRE FACULTY OF ARCHITECTURE
- 15:41:29 – 12-03-2010 – 87 **AMBU - PRIORITY 1** – 3122 - FIRE FACULTY OF ARCHITECTURE
- 15:41:45 – 12-03-2010 – 87 **POLI - PRIORITY 1** – 3122 - FIRE FACULTY OF ARCHITECTURE

Even though the events in the loads are roughly the same, there are some differences between the loads, mainly due to the use of DIOS as the new information management system in Load B. The main difference is the way of coordinating information management processes in disaster situations. Table 8.4 provides an overview of differences between load A and B. The design principles proposed in chapter 6 and embodied in the prototype (see chapter 7) reside in Experiment B. This includes the role of orchestrators (instead of information managers), DIOS instead of Word-based situation reports, information rating capabilities and network wide reach back and information request (using DIOS).

**Table 8-4: Some differences between Experiment A and Experiment B**

| Variable | Experiment A | Experiment B |
|---|---|---|
| Type of Sitreps | Team Sitrep<br>Column Sitrep | Network Sitrep: everyone can contribute to the same Sitrep |
| Sitrep-form | Team Sitrep in MS WORD<br>Column Sitrep on paper forms | Network Sitrep in DIOS |
| Information Synchronization | Asynchronous information sharing thru paper Sitreps | Synchronous information sharing using DIOS: everyone can see the same information immediately |
| Facilitator Roles | Mailman<br>Journalist | DIOS Assistants (4x)<br>Journalist |
| Rating of Information | None, not required | Available in DIOS |
| Memory of Information | Fragmented in paper Sitreps | Aggregated in DIOS |
| Location maps | On paper (large map on table) | Projection in DIOS |
| Information supply | Through the Mailbox, on paper | Real Time supply in DIOS |
| Reachback | Inter and intra-agency | Network |
| Location of disaster | Warehouse Complex | University Campus |
| Tasks of the Information Manager (round 1) versus the Information Orchestrator (round 2) | Generate paper Sitrep and send to other teams via MS WORD and Gmail | Orchestrate Sitrep in DIOS, prioritize and handle info request directly using DIOS, communicate and rate the reliability of the information in DIOS |

Table 8-4 lists some of the main differences in the experimental loads of both rounds. In the following section, we discuss the data collection process, the results and the findings of the gaming-simulation session with professionals.

## 8.4 Qualitative data collection and findings

As discussed in chapter 2, our strategy was to collect both qualitative and quantitative data from our gaming-simulation. As such, we employed three instruments for data collection purposes including:

1) *Observational notes*. Prior to the gaming-simulation, we briefed a team of six observers. The observers knew about the scenario of the game and knew some examples of IQ and SQ issues that might occur. The observers were each dedicated to a specific team. The observers were equipped with a predefined observation protocol, identical to the one we used during the field studies (see Appendix-B).The observers were also equipped with a photo camera allowing them to capture some impressions during the game. As a result, we ended with 12 (6 times 2) completed observational notes.

2) *Video recording*. Before the start of the gaming-simulation, we installed six video cameras, one in each room. The video cameras also captured voice conversations and narratives. We told the participants about us filming them for research purposes. As such, the cameras videotaped the interactions in each

team allowing us to look back on these interactions whenever necessary. In the end, we collected approximately 18 hours (6 x 3 hours) of video. This was almost 36 gigabytes of video material (approximately 6 gigabytes per team).

3) *Participant notes.* The participants each had a manual, which included ample space for note taking during the rounds and during the debriefing sessions. Since we encouraged the participants to take notes and return the manuals after the gaming-simulation, the participant notes were a significant source of qualitative data. Also, we were able to recollect most of the messages and information request-response forms send in round 1. Especially the later form contained some information we could relate to the IQ and SQ issues in round 1.

We discuss the results of the qualitative data collection in section 8.5. First, we discuss the surveys used for quantitative data collection

### 8.4.1   Round 1

In round one, three of the six observers noted some confusion on the exact location of the warehouse (Gamma) and on which floor the fire was (first floor or ground level) (t=14:01). After watching the video recordings, we found that the confusion existed in the control room of the fire department, the COPI and the GVS. The video recordings also show that the confusion was settled after some conversations between field unit officers (a kind of 'motorkap overleg') and information exchange (via the paper forms). Later, the observer focused on the field units also noticed some confusion about the decided affected (source) area, something that should have been decided by the GVS (t=14:03). It seems this information did not reach the field units. Another issue noted by the observer focused on the field units was the asymmetry in the information they received from the respective commanders in the COPI. For instance, the police department received instructions to help evacuate the warehouse 9 minutes after the fire department had received this information. Consequently, the fire department had already started to evacuate, without the assistance and knowledge of the police department (t=14:07).
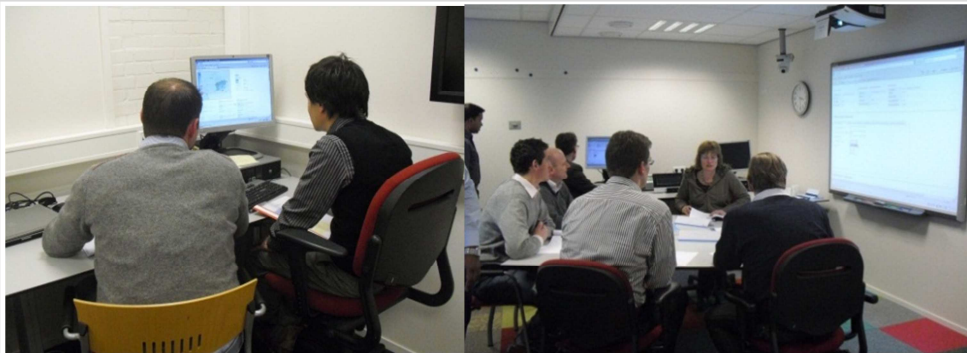
A noteworthy example of incomplete information was observed in COPI team. The commander of the medical services shared information he received from his field units on the death toll. He mentioned that eight fatalities were counted (t=14:08). What was missing here is the time that these counts were made and how these people died (because of the smoke or heat from the fire?). Moreover, the commander of the fire department had not received any information on this issue. In addition, the COPI was quite interested about any chemicals or toxic that might have been in the warehouse and whether or not they are flammable. The video recordings show that a request for this information was send to the field units of the fire department (t=14:11). Yet, since the respondents on the field level did not have this information and were not able to contact the store manager, this information was never send back. The observer in the GVS noted (t=14:13) that the commander of the medical services had received very little information from her subordinate in the COPI. The video recordings also show that the leader of the GVS (the Mayor) started to get a bit nervous (t=14:18) because he had so little info on the exact situation on the field while he was expected to speak to the press soon. The observer in the COPI also noted that no response was given to the information request send to

the fire department regarding the potential of asbestos being released because of the fire (t=14:22).

## 8.4.2  Round 2

All of the observers noted that there were far less discussions in round two compared to round one. The video recordings showed that the first minutes of round two were dominated by the introduction of DIOS and the interactions between the orchestrator and this prototype (t=14:46). The relief workers were particularly curious about the information displayed in DIOS and the functionalities provided by this prototype. Some comments from the participants in the COPI included that the user interface was simple and intuitive. The observer in the GVS noted that after some general reelections on the prototype, the Mayor insisted the team moved on with deciding on how to repress the disaster at the University Campus. The following pictures illustrate the use of DIOS.

**Figure 8-5: Impressions of ECC Operators (left) and GVS members (right) using DIOS**



The observer at the field units noted that the police officers were content with the information request functionality in DIOS and explained that this was faster than via the radio (situation in practice). A noteworthy statement by the commander of the police in the GVS is that using DIOS everyone made less redundant information requests. He explains to his team that he has experienced many redundant information requests, both on an intra-agency level and on the various echelons (t=14:57).

The observer at the emergency response center of the fire department noted that the officers felt that there was much information in DIOS, but much of it was not directly relevant for them (t=15:01). Instead, this participant would rather use an application displaying information that was only relevant for his agency. Around 15:07 the observer in the GVS noted that the GRIP level was increased to level 3 by the field units of the fire departments. This resulted to some agitation within the GVS since the commanders there felt that it was not up to the field units to decide on the grip level. Around the same time, the notes of the observer in the emergency response center of the medical services indicate that the operators were not satisfied with the way their information response was handled in DIOS. They

seem to have made a request for information regarding the number of ambulances on site and have not received any response, even after repeating the request.

The observer in the emergency response center of the police department noted some discussion on the rated information (about the number of casualties). One of the participant explained that rating information was a nice idea, but that relief workers need to be critical on what that rating means since information that is rated low could also be important (t=15:09). A noteworthy situation reported by the observer in the GVS was the frustration of the Mayor with all the new information coming in DIOS on a continual basis. The Mayor mentioned that to some extent, the application distracted the decision-making process. While the Mayor acknowledges that all real-time updates were interesting, he reminded the team that they were activated not to monitor information updates but to take decisions, albeit based on information that was already out of date (t=15:16). The Mayor further explained that such an application should not dictate the structure of the decision-making process in a multi-agency team.

## 8.5   Quantitative data collection and findings

This section reports on the quantitative data collected during the gaming-simulation with professionals. This section splits into three subsections. First, we discuss the data collection using surveys. Then we discuss how the data was prepared and analyzed. This section concludes with some findings obtained from the quantitative data.

### 8.5.1   Data collection

As part of our quantitative data collection approach, we used surveys as an instrument to assess the IQ and SQ values perceived by the participants after each round. The surveys used for the gaming-simulation are based on the same items used for the field studies in chapter 4. Where necessary, we modified items in order to match to context, experimental load, and structure of the gaming-simulation. The table below shows the components of both surveys.

**Table 8-5: Parts of the survey**

| Part | Description | R1 | R2 |
|---|---|---|---|
| A. General Questions | Demographics of the respondents | X | |
| B. Evaluation of the Game Round | 8-10 questions concerning the gaming-simulation itself | X | X |
| C. Evaluation of Information Quality | 20 questions on the assessment of information quality | X | X |
| D. Evaluation of System Quality | 19 questions on the assessment of system quality | X | X |
| E. Evaluation of DIOS functionalities | 12 questions on the assessment of the propositions of DIOS | | X |
| F. Suggestions and Comments | Open fields for comments | X | X |

The survey included six parts. As mentioned, both surveys for round 1 and 2, were included in the participant manuals. Appendix-D provides the total set of items in the survey. The surveys were identical, except for a few general items and extra items in the second survey. Furthermore, several system functionalities are evaluated in part E of the survey. In part B, C, D and E, we again used a 7-point

Likert scale (similar to the field studies) to measure the opinion of the participants with respect to the formulated statements. The next subsection will elaborate on the data preparation.

### 8.5.2   Data Preparation

The first step in the data preparation process was to create a codebook. The codebook shows how questions from the surveys are translated into variables, what values these variables can have, which value labels are assigned and what measurement level each variable has. For analyzing the data derived from the experiment, we used two software packages:

1. *SPSS Statistics 17.0:* we used this data-analysis tool for performing several statistical analyses. We performed the reliability analysis and the Wilcoxon Signed Rank Test with this software tool.
2. *MS Office Excel 2007:* we used Excel 2007 for generating descriptive tables, histograms and pie charts.

Since we included three different statements for some of the IQ and SQ dimensions in our survey, a reliability analysis was required for checking whether statements that initially belong together still measure the same construct. For each set of items, the SPSS reliability analysis returns a value for Cronbach's Alpha. Cronbach's Alpha is a measure for the internal reliability of a scale. There are several rules of thumb available for the Cronbach's Alpha coefficient, > 0.9 is considered: Excellent; > 0.8: Good; > 0.7: Acceptable; > 0.6: Questionable; > 0.5: Meager, and < 0.5: Unacceptable (George & Mallery, 2003). We adhere to these rules when interpreting the reliability scores below. The tables below show the results of reliability analysis for dimensions of both round 1 and 2.

| Table 8-6: Reliability analysis - Round 1 | | |
|---|---|---|
| **IQ/SQ Dimension** | **IQ/SQ Statements** | **Cronbach's Alpha** |
| IQ_TIMELINESS | R1_IQ_TIMELINESS_1 R1_IQ_TIMELINESS_3_REC | .804 |
| IQ_CORRECTNESS | R1_IQ_CORRECTNESS_2_REC R1_IQ_CORRECTNESS_3_REC | .534 |
| IQ_COMPLETENESS | R1_IQ_COMPLETENESS_1 R1_IQ_COMPLETENESS_2_REC | .682 |
| *IQ_OVERLOAD* | *Scale could not be constructed* | *Negative alpha* |
| IQ_RELEVANCY | R1_IQ_RELEVANCY_1 R1_IQ_RELEVANCY_2_REC R1_IQ_RELEVANCY_3_REC | .766 |
| IQ_CONSISTENCY | R1_IQ_CONSISTENCY_2_REC R1_IQ_CONSISTENCY_3_REC | .506 |
| *SQ_RESPONSETIME* | *Scale could not be constructed* | *.222* |
| SQ_ACCESSIBILITY | R1_SQ_ACCESSIBILITY_1 R1_SQ_ACCESSIBILITY_3 | .613 |
| SQ_SATISFACTION | R1_SQ_SATISFACTION_1 R1_SQ_SATISFACTION_2 | .859 |

The table above shows the results for the reliability analysis for round one. The items in italic indicate that the set of items used scored low in terms of reliability. The table below outlines the results of the reliability analysis for round two.

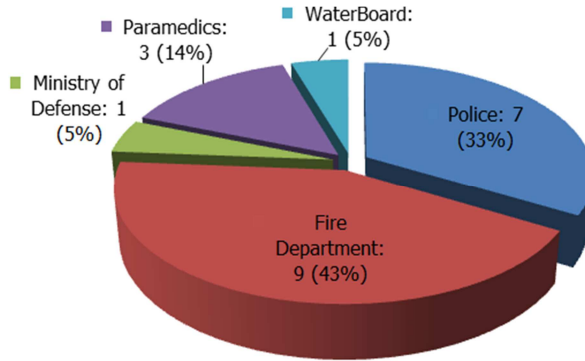| Table 8-7: Reliability Analysis - Round 2 | | |
|---|---|---|
| **IQ/SQ Dimension** | **IQ/SQ Statements** | **Cronbach's Alpha** |
| IQ_TIMELINESS | R2_IQ_TIMELINESS_2_REC R2_IQ_TIMELINESS_3_REC | .713 |
| IQ_CORRECTNESS | R2_IQ_CORRECTNESS_2_REC R2_IQ_CORRECTNESS_3_REC | .637 |
| IQ_COMPLETENESS | R2_IQ_COMPLETENESS_2_REC R2_IQ_COMPLETENESS_3_REC | .657 |
| IQ_OVERLOAD | *Scale could not be constructed* | *.208* |
| IQ_RELEVANCY | R2_IQ_RELEVANCY_2_REC R2_IQ_RELEVANCY_3_REC | .726 |
| IQ_CONSISTENCY | R2_IQ_CONSISTENCY_1 R2_IQ_CONSISTENCY_2_REC R2_IQ_CONSISTENCY_3_REC | .514 |
| SQ_RESPONSETIME | R2_SQ_RESPONSETIME_1 R2_SQ_RESPONSETIME_2_REC | .730 |
| SQ_ACCESSIBILITY | R2_SQ_ACCESSIBILITY_2 R2_SQ_ACCESSIBILITY_3 | .815 |
| SQ_SATISFACTION | R2_SQ_SATISFACTION_1 R2_SQ_SATISFACTION_2 | .599 |

The scores in italics are definitely unacceptable. The other scales are in the range of .506 - .859. This range of values is not unacceptable and therefore, these scales are used for showing the results in the next paragraph. We can however *not* use the following scales when interpreting the results since these have proven to be unreliable:

1. Round 1: IQ_OVERLOAD
2. Round 1: SQ_RESPONSETIME
3. Round 2: IQ_OVERLOAD

The next subsections will discuss the quantitative results of the gaming-simulation session at the Police Academy. These results are based on scales that were defined in the previous section. First, the next subsection presents some background information on the sample of participants.

### 8.5.3 Background of the participants

Part A of the survey employed for round one asked some questions on the background of the participants. Participants were asked which organization they worked for, how long they worked there and how often they have been involved in responding to a serious disaster situation (GRIP 1 or higher). We had a sample size of 22 respondents since two respondents have not returned useful survey responses. Figure 8-7 shows some figures on demographic data of the respondents. What we can conclude with respect to the sample is that we had a very heterogeneous group of relief workers that participated in this quasi-experiment

**Figure 8-6: Organizations represented in sample (N=22)**



The heterogeneity in relief workers makes the results regarding the IQ and SQ dimensions even more interesting as this group of relief workers is a fair representation of relief workers that are present during disaster response in the Netherlands. The following figure presents the work experience of the participants that were involved in our gaming-simulation.

**Figure 8-7: Experience of the participants (N=22)**



Figure 8-8 above shows that our sample of relief workers included some considerable experience in working at their organization. The majority of participants have more than 5 years of experience. Of course, one cannot immediately state that they also have a lot of experience with disaster situations, we can however say that this sample consists of relatively experienced relief workers, who are probably already much familiarized with the way of working in their own organization. The

following graph does however give some numbers on the level of experience in dealing with disaster response.

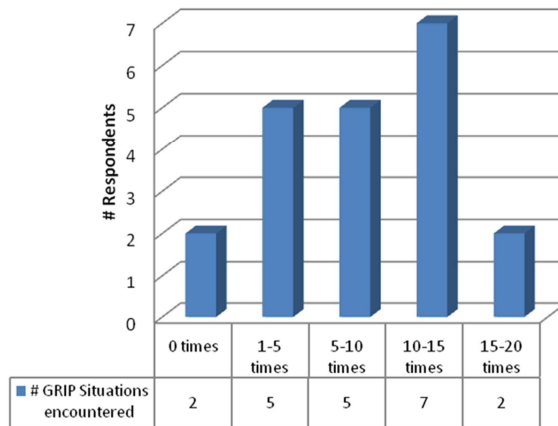**Figure 8-8: Number of GRIP situations encountered by participants (N=22)**



Figure 8-9 shows that most participants already encountered a GRIP situation of GRIP 1 or higher. Only two out of the twenty-two participants had no prior experience with multi-agency disaster management. As such, we can conclude that we had a representative sample of relief workers participating in our gaming-simulation. In the next sections, we elaborate on the results with respect to IQ and SQ dimensions in round 1 and 2.

### 8.5.4 Quantitative results – IQ dimensions

In this section, the results of IQ dimensions of both round 1 and 2 are portrayed. We focus on the means and standard deviations (SD). In section 8.5.6 we discuss whether the differences between the means of both round are statistically significant using the Wilcoxon Signed Rank Test. First, the table below outlines the scores on the IQ dimensions for round 1 and 2.

**Table 8-8: Results - IQ Dimensions (N=22)**

|              | Round 1 |      | Round 2 |      |
| ------------ | ------- | ---- | ------- | ---- |
|              | Mean    | SD   | Mean    | SD   |
| Timeliness   | 3.80    | 1.53 | 4.29    | 1.44 |
| Correctness  | 4.33    | 0.94 | 5.00    | 1.19 |
| Completeness | 3.46    | 1.23 | 3.71    | 1.20 |
| Relevancy    | 3.71    | 1.44 | 3.78    | 1.35 |
| Consistency  | 4.63    | 1.31 | 4.00    | 0.89 |
| Format       | 2.55    | 1.36 | 3.70    | 1.58 |

When comparing the means over both rounds we can conclude that round two shows higher scores for the measured IQ dimensions, except for IQ-Consistency. Note that the standard deviation for this dimension has also decreased in the second round. The fact that inconsistent information is easier to spot in DIOS might explain the slight decrease in IQ-Consistency. The numbers show that the information shared in round 2 was more up-to-date then the information in round 1. Another noteworthy number is the increase in the average scores for IQ-Format and IQ-Correctness. It seems that the participants perceived the information posted in DIOS to be in a more adequate format and more correct than was the case in round one.

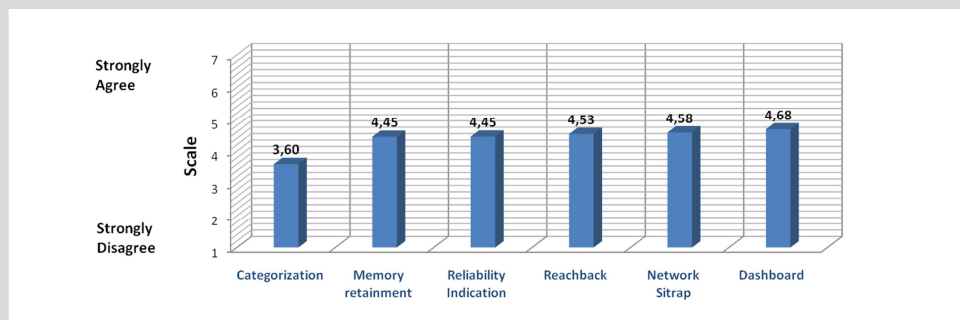## 8.5.5 Quantitative results – SQ dimensions

The following table outlines the average scores and standard deviations for the SQ dimensions.

| Table 8-9: Results - SQ Dimensions (N=22) | | | | |
|---|---|---|---|---|
| | Round 1 | | Round 2 | |
| | Mean | SD | Mean | SD |
| Accessibility | 2.47 | 1.03 | 4.53 | 1.33 |
| Satisfaction | 2.53 | 1.40 | 3.41 | 1.35 |
| Response time | 2.15 | 1.22 | 3.75 | 1.61 |
| Info Sharing Support | 2.98 | 1.33 | 4.15 | 1.22 |
| Notification | 2.42 | 1.06 | 3.89 | 1.34 |
| Feedback | 4.20 | 1.27 | 4.78 | 1.63 |

Table 8.9 shows higher differences between means for the SQ dimensions than table 8.8 showed for the means regarding the IQ-dimensions. Based on these numbers, we could conclude that the impact of netcentric information orchestration on the SQ dimensions was more apparent to the participants than the impact on the IQ dimensions. The numbers indicate that in round two, information was more accessible. We also see a relatively high difference for the SQ-response time over both rounds, which could also explain the higher value for the IQ-Timeliness in the previous table. The DIOS prototype also did better in information sharing support, notification of changes and providing feedback on the quality of the information shared.

## 8.5.6 The functionalities of DIOS

In the final part of the second survey, we requested the relief workers to reflect on some statements about the functionalities of DIOS. Functionalities of DIOS included the categorization of information, rating information and the dashboards. We included these statements in the questionnaire since we wanted to obtain some additional data on how the participants valued the functionalities provided by DIOS. The list of statements can be found in Appendix-D. The following figure presents the results of the evaluation of the DIOS features.

**Figure 8-9: DIOS features evaluation (N=22)**

The numbers shown in the figure 8-10 are quite moderate, relief workers did not really favor the DIOS functionalities, nor did they dislike or disapprove of them. One exception could be the categorization of information in DIOS, it seems that on average, this functionality was not sufficiently valued by the participants. An explanation for this may be found in the fact that DIOS includes all information for all relief agencies while some participants have indicated that the rather have an overview of information directly relevant for their own agency (see section 8.4.4). Surprisingly, we did not find a high average score for the extensive reach-back capabilities provided in DIOS (i.e., access to social networks and third party data). The respondents have scored the network-sitrep functionality and the dashboard functionality more positively than the other functionalities.

### 8.5.7   Wilcoxon signed rank test

The Wilcoxon Signed Rank Test is a non-parametric statistical test in which the median difference of a pair of variables is tested (Crichton, 2000). As Wilcoxon states in his article, we can use ranking methods to 'obtain a rapid approximate idea of the significance of the differences in experiments of this kind' (Wilcoxon, 1945). The Wilcoxon-test has a parametric alternative called the Student-t paired samples test. However, this parametric student-t test requires that the data follows a normal distribution and a sample size beyond 30 cases (Hair, et al., 1995). This is not the case in this dataset, and because of the low sample size (N=22) we cannot approximate a normal distribution by using the Central Limit Theorem (to do so, a minimum of N = 30 is necessary). Therefore, a non-parametric alternative was the only alternative for this dataset.

Table 8-10 presents the results of the Wilcoxon-test. For each pair of dimensions (round 1 and round 2), a significance level is provided in the table, telling us whether the mean in round 1 significantly differs from the mean in round 2. In case the significance level is <=0.05, the difference between round one and two is statistically significant. This is the case for IQ – Timeliness, IQ – Correctness, IQ – Consistency, SQ – Accessibility and SQ-Response time. The other pairs do not have a significant difference; this tells us that the difference can be coincidence. This however does not mean that there is no observable difference for these dimensions as illustrated in figure 8.11. Concluding this section, we can now state that there is a positive significant difference between round 1 (hierarchical approach) and round 2

(netcentric orchestration approach) on the dimensions: IQ-Timeliness, IQ-Correctness, SQ-Accessibility and SQ-response time.

| | Table 8-10: Wilcoxon Signed Rank Test | | |
|---|---|---|---|
| | **Dimension** | **Z** | **P-value** |
| Information Quality | *Timeliness* | *-1.017[a]* | *.009\*\** |
| | *Correctness* | *-1.805[a]* | *.041\** |
| | Completeness | -.966[a] | .334 |
| | Relevancy | -.543[b] | .587 |
| | *Consistency* | *-1.962[b]* | *.050* |
| | Format | -1.699[a] | .096 |
| System Quality | *Accessibility* | *-3.268[a]* | *.001\*\*\** |
| | Satisfaction | -1.716[a] | .086 |
| | *Response time* | *-1.022[a]* | *.027\** |
| | Info sharing support | -.813[a] | .399 |
| | Notification | -.623[b] | .589 |
| | Feedback | -.877[a] | .433 |

We can also conclude that there is a negative significant difference on the IQ-Consistency dimension. In other words, to answer the last sub-question of this research, netcentric information orchestration has a positive effect on the dimensions IQ-Timeliness (3.80 → 4.29), IQ-Correctness (4.33 → 5.00), SQ-Accessibility (2.47 → 4.52) and SQ-Response time (3.75 → 2.15) compared to using a hierarchical approach. However, sharing information in based on a netcentric orchestration architecture has a statistically significant negative effect on the dimension IQ-Consistency (4.63 → 4.00).

## 8.6  Summary

This chapter discussed the results of our quasi-experimental gaming-simulation with professionals. Our goal was to evaluate the extent to which the principles behind netcentric information orchestration would assure higher levels of IQ and SQ for relief workers during disaster response. For this purpose, we used for a particular type of quasi-experiment, called a single group pretest posttest quasi experiment. Following this setup, we divided the gaming-simulation to in two rounds. In the first round, we simulated information sharing based on the currently used hierarchical approach to information management.

In the second round, relief workers tried to resolve a different disaster and shared information based on the netcentric information orchestration approach presented in Chapter 6. The principles behind netcentric information orchestration were embodied in DIOS and in the role of the information orchestrator. During the gaming-simulation, we collected both qualitative and quantitative data based on observation notes, video recording, and survey data. The analysis of the survey data shows a positive and statistically significant improvement on the scores of IQ-Timeliness, IQ-Correctness, SQ-Accessibility and SQ-Response time. Interestingly, the data also reveals that the dimensions IQ-Overload (this dimension had however no statistically constructed scale; we observed the values of the statements separately) and IQ-Consistency deteriorated in particular.

Apart from the quantitative results on IQ and SQ dimensions, we also noted some interesting issues regarding the attitude and experiences of the relief workers during the session. We observed that several relief workers had a somewhat negative stance towards network-centric operation in general, even before the gaming-simulation session. This may be the result of the active imposition and promotion of CEDRIC as a netcentric information system by the Ministry of Internal Affairs of the Netherlands.

# 9 Conclusions

*"Reasoning draws a conclusion, but does not make the conclusion certain, unless the mind discovers it by the path of experience."*

Roger Bacon, English philosopher (1214-1294)

This dissertation presents tested design principles for assuring information quality (IQ) and system quality (SQ) during disaster response. The *societal driver* for conducting this research is rooted in the many disaster evaluation reports that reveal problems regarding IQ and SQ in public safety networks (PSNs). Committees that have investigated the response to disasters repeatedly concluded that relief workers did not have the right, relevant and up-to-date information during disaster response. Such reports have also revealed problems regarding the quality of information systems (IS) used, including their response time, reliability and information access capabilities. Together, poor IQ and SQ have significantly hampered relief workers in their response efforts, sometimes leading to dangerous situations for relief workers and civilians. From a societal perspective, this research was required not only because of the alarming number of IQ and SQ related problems costing time, money and human lives during disasters, but also because stakeholders (i.e., relief workers, IS architects, policy makers and software vendors) were previously left unguided in finding tested solutions for these issues.

The *theoretical driver* for this research stems from the lack of design theories (i.e., guiding principles) for assuring IQ and SQ in PSNs. In addition, insights on the configuration of IS architectures in practice are scarce, demanding some demystification through empirical analysis. Two theories providing pathways to assuring IQ and SQ surface from literature. These two theories are coordination theory and Network Centric Operations (NCO). A *pathway* is a specific progression of one or more concepts in the evolution of a theory. Each pathway is a dynamic and developmental process, which may include several stages. We treat the two theories as 'kernel theories' since they originate from domains other than disaster response and are not directly applicable in the context of PSNs. While the application of coordination theory is growing, NCO has become a buzzword amongst IS architects and policy makers in PSNs, despite the lack of scientific research on the implications and limitations of NCO. Based on the stated societal and theoretical drivers, the main objective of this dissertation is to *synthesize and evaluate IS design principles that assure IQ and SQ in PSNs during disaster response.*

As a dissertation from the faculty of Technology, Policy, and Management of the Delft University of Technology, we conducted this research from a sociotechnical perspective. As stated in Chapter 1, this perspective recognizes the importance of human roles, their tasks and capabilities while emphasizing the role of information technology (IT) as enabling tools in multi-agency information management processes. This perspective resonates with our position that the social and

technical subsystems in PSNs are interdependent and must be jointly analyzed, designed and evaluated in order to assure IQ and SQ. Moreover, this perspective allows us to gain a holistic understanding of the complex and unpredictable interactions between several agencies and supporting technologies in PSNs. This chapter proceeds by presenting the conclusions of this dissertation. The conclusions are clustered in accordance to the four research questions discussed in Chapter 2.

## 9.1 Research question 1: establishing the knowledge base

In accordance with the research objective stated earlier, we needed to establish two foundations in our knowledge base. The first foundation is on defining and measuring IQ and SQ. Studies that have investigated disaster response efforts mention several examples of poor IQ and SQ. However, since previous studies were mainly focused on the performance of relief agencies, both constructs were often left undefined and not operationalized (a construct is a variable that is not directly observable and must be observed through its indicators). Even though we intuitively knew what IQ and SQ mean, scientific research requires a framework that allows for the systematic measurement of IQ and SQ issues. This framework needed to not only capture a wide range of IQ and SQ dimensions, it also needed to provide tested indicators (items) for measuring IQ and SQ in practice. Accordingly, the first subquestion (1a) asked: *What is a useful and tested framework provided in the literature for studying information quality and system quality in public safety networks?*

By means of literature research, we have found a considerable number of scientific publications on defining and measuring IQ and SQ. As a scientific construct, the construct of quality has come a long way since first coined by Frederic Taylor (1947, originally 1911). Since then, the quality construct has expanded from a 'hard', production and technology related construct, to a 'soft' construct that also captures the experience of customers and employees. With the rise of information as a 'resource' and information technology (IT), it was only natural that the quality of information and the supporting IT would become a subject of scientific interest. Consequently, there are several perspectives, frameworks and definitions of IQ and SQ, some of which are included in Chapter 4. In was not until the seminal work by Delone and Mclean (1992) that the constructs of IQ and SQ were brought together in a single theoretical model. As foundation of the Information System Success Theory, this model treats IQ and SQ as antecedents for the success of ISs in firms. In this model, both constructs are multi-dimensional and entail dozens of variables, not all of them being mutually exclusive. We found that both constructs entail a mix of objective and subjective scales, some of which can be assessed only by information users (e.g., relief workers). Timeliness of information, for instance, can be measured using an objective time measurement instrument such as a stopwatch, whereas the subject (i.e., relief worker) in question is the only person that can say something about the relevancy of a particular information object. This conclusion emphasized the need to collect empirical data (on IQ and SQ issues) directly from relief workers and in the context of a disaster. It also meant that our evaluation cycle would demand the incorporation of real (as opposed to artificial) relief workers.

Since the paper by Delone and Mclean (1992), multiple scholars have adapted and extended IQ and SQ as antecedents for ISs success. Remarkably, scholars again studied IQ and SQ separately, probably because these constructs are too comprehensive to study in a single paper. Therefore, several frameworks are

provided in the literature for studying IQ and SQ, none of which providing a single framework for studying IQ and SQ. Nevertheless, striving to answer question 1a, we developed our own framework consisting of IQ and SQ dimensions that were tested in other studies. This framework relies heavily on Lee et al. (2002) and Nelson et al., (2005) whom have provided items for assessing IQ and SQ and have tested these items using empirical data. Therefore, as an answer to question 1a, our framework includes IQ dimensions such as correctness, completeness, timeliness, relevancy, consistency and SQ dimensions such as response time, accessibility, satisfaction and reliability. We used this framework during our empirical research discussed in chapters 4 and 5. Note that we were not aiming to contribute to the definition and measurement of IQ and SQ, especially since there are already several contributions that have focused on this. Instead, we were in search of a framework, including clearly defined and empirically tested IQ and SQ assessment items that would allow us to measure IQ and SQ issues in PSNs.

The second foundation we needed to establish in our knowledge base was on pathways for assuring IQ and SQ. Our 'first hunch' was that the literature on NCO and Coordination Theory would provide pathways for assuring IQ and SQ in PSNs. Here, we consider a pathway as a stream in a specific theory that helps scholars in purposefully navigating through the existing body of knowledge on that specific theory. As such, a pathway is a specific progression of one or more concepts in the evolution of a theory. Each pathway is a dynamic and developmental process, which may include several stages. We regarded NCO and coordination theory as kernel theories since a preliminary analysis of both theories did not reveal explicit design principles for assuring IQ and SQ. Instead, we expected that these theories would provide 'pathways' that, when navigated with our empirical knowledge, would allow us to synthesize design principles. Stating a first hunch is quite common in design and prescription oriented research since it allows the researchers to focus, review literature more thoroughly and state expectations earlier in the research (Verschuren & Hartog, 2005). Drawing on this first hunch, question 1b asks *which pathways are provided in coordination theory and netcentric operations theory for assuring IQ and SQ in public safety networks?* Based on our examination of both kernel theories, we found seven pathways. We reflect on the pathways provided in both kernel theories in the following sub-sections.

### 9.1.1 Pathways from coordination theory

Through an extensive literature review, we found that coordination theory is a well-studied and applied theory in IS and other domains. Acknowledging that several constructions and operationalizations of coordination theory exist in the literature, the most common construction in the IS field is the management of interdependencies between actors, goals, and activities by means of various mechanisms (Malone & Crowston, 1994a). While this definition was clear on what is to be coordinated (interdependencies), it did not help us to understand how information can be coordinated in such a way that IQ and SQ can be assured. A more detailed examination of this and other definitions for coordination led us to conclude that several resources (i.e., humans, equipment and information) and processes (i.e., resource allocation, rescue operations and information management) can be coordinated via different roles (i.e., team leader, information manager and IT operator) and objects (i.e., uniforms, standards and IT). Based on this perspective on coordination, our

research focuses on the coordination of information (as a resource) and information management (as a process) through roles and objects.

Often regarding the combination of roles and objects as mechanisms for designing coordination structures, scholars have long debated the level of centralization or decentralization of these mechanisms as important steering instruments for coordination. Centralization has often been associated with benefits such as accountability, control and economic efficiency whereas decentralization has often been associated with benefits such as flexibility, redundancy and speed. King (1983) has brought some clarity in this debate by identifying three dimensions to the centralization issue: (1) concentration of decision-making power, (2) physical location, (3) function or the position of an activity or responsibility. These dimensions proved to be very useful for us in navigating the large body of knowledge on coordination. In the spectrum of archetypical organizational designs (Mintzberg, 1980), hierarchies are fully centralized for all dimensions, whereas networks are fully decentralized for all dimensions. However, as stated in chapter 1, PSNs are special type of design that includes a hybrid form of these dimensions. Considering the first dimension, we were not looking for pathways on the centralization or decentralization of decision-making power since we had little design space for this dimension. As discussed in chapter four, decision-making power in PSNs is hierarchically centralized in multi-agency teams activated on the strategic, tactical and operational echelons. Considering the second dimension, we also have little design space since PSNs include several, physically distributed teams. Considering the third dimension, we were looking for pathways on decentralizing information management activities and responsibilities in PSNs. The field studies discussed in Chapter 5 reveal that the information management capabilities are currently centralized in the emergency control rooms in PSNs, leaving the multi-agency teams with very few capabilities for directly collecting and sharing information. Using these three dimensions, we were able to find, led us to four pathways for assuring IQ and SQ from coordination theory.

The first pathway we drew from coordination theory is orchestration. Whereas there is no single and universally accepted definition or framework for orchestration, scholars seem to agree on the goal of orchestration. Drawing on the example of a music orchestra with a variety of artist instruments, the goal of orchestration is to facilitate a variety of roles and objects to function in concert (a coherent way that serves the purpose of all stakeholders). As such, this pathway routes us to finding ways to maximize the benefits of decentralization, while retaining the benefits of centralization. The first mentioning of orchestration can be traced back to Neurath (1946). As argued in chapter three, orchestration is a hybrid and heterarchical form of coordination already studied in several areas, including e-government, supply chains and business networks orchestration. We use the term 'heterarchical' because there is no hierarchy of information managers as orchestrating units. Heterarchical control structures have distributed locally autonomous entities that communicate with other entities without the master/slave relationship found in a hierarchical architecture. According to Dilts et al., (1991) the field of distributed computing is a source for a number of justifications for the principles of heterarchical control architectures. Implying the decentralized function of information management in a decentralized and physically distributed network structure, orchestration is not about the first dimension of King (1983), it's primarily about the position of the information management responsibilities in a PSN.

As such, orchestration does not require hierarchical organizations (i.e., police, fire department and medical services) to fully centralize authority and decision-making when forming a public safety network, and yet decentralize information management activities such that the IQ and SQ can be assured beyond organizational boundaries. This special form of coordination appealed to our interest since it does not dictate the destruction of variety in the current IS landscape of PSNs. Resting on Ashby's law of 'requisite variety' (Ashby, 1958), we argue that some variety in roles and objects is necessary, especially when dealing with complex and unpredictable situations such as disasters. Hence, we argue that uniformity should only be pursued when we have definitely found that single solution that always works for all sorts of disasters. This does not mean that orchestration does not require any standardization. While only demanding some level of standardization in message exchange (for instance using web-services), orchestration allows for co-existing of several (proprietary, legacy or preferred) IS components and technologies.

The second pathway we drew from coordination theory is boundary spanning. Boundary spanning refers to the activity of making sense of information to expand the knowledge of a given organizational context (Lindgren, et al., 2008). Roles and objects that link their organizations with others are referred to as boundary spanners (Aldrich & Herker, 1977; Thompson, 1967). Given the fact that PSNs emerge from several organizations with no dependency prior to disasters, boundary spanning appealed to our interest as a pathway for assuring IQ and SQ. After examining existing work, we found that boundary spanners should possess knowledge of the relevance between various information and their linked organizations and make decisions concerning the distribution of gathered information. They convey influence between the various groups and at the same time represent the perceptions, expectations, and values of their own organizations to those groups (Friedman & Podolny, 1992). In addition to boundary spanners, information systems acting as "boundary objects" have also been hailed as a critical enabler of boundary spanning (Levina & Vaast, 2005). Star & Griesemer (1989) specify boundary objects as "objects that are plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites." The term has also been used to refer to the potential of ISs to facilitate boundary spanning (i.e., Lindgren et al., 2008) in the IS field. Accordingly, boundary objects may include physical product prototypes, design drawings, shared IT applications, engineering sketches, standardized reporting forms, or even shared abstract constructs such as product yield. Boundary objects act as 'brokers' between interactions with other organizations, but at the same time they act as gatekeepers, selecting and filtering information. For boundary spanning to emerge, a new joint field of practice must be produced (Levina and Vaas, 2005), which can be a shared IS. Many ISs do not become boundary objects in practice, as human agents do not see their local usefulness or fail to establish a common identity for them across sites. Therefore, boundary spanning, thus the roles of boundary spanners and boundary objects as well, become extremely important in PSNs where a large number of heterogeneous agencies have to develop a common operational picture and respond jointly to the effects of a disaster.

The third and fourth pathway we drew from Coordination Theory come from March and Simon (1958). These pathways are 'advanced structuring' and 'dynamic adjustment'. The rationale behind these pathways is that organizations (i.e., relief agencies) that operate in dynamic environments, need to seek to consciously

lay out prescribed activities by planning in advance, while at the same time need to supplement these with spontaneous ongoing adjustment to cope with unforeseen scenarios (Beekun & Glick, 2001). Coordination may thus be based on advanced structuring, or coordination by plan, and dynamic adjustment, or coordination by feedback. While literature (i.e., Tan & Sia, 2006) is somewhat inconclusive on the results of these pathways, we concluded that these pathways emphasized the development of specific IS capabilities. In this light, advance structuring suggests the development of preemptive and protective capabilities prior to a disaster. Loose coupling is an example of a preemptive capability, whereas dependency diversification is an example of a protective capability. The idea here is that the upfront development of IQ and SQ assurance capabilities will require fewer efforts to assure IQ and SQ during disaster response. Following this pathway, relief agencies can equip themselves with the dexterity required for preemptive capabilities before the nature of the disaster is known, consciously creating a range of information coordination services before they are needed. Relief agencies can also use redundancy mechanisms, such as information or resource buffers, as a protective measure to guard against a potentially damaging situation and to allow a strategy to remain viable in spite of changes in the environment. Complementary to this pathway, the pathway of dynamic adjustment suggests the creation of exploitative and corrective capabilities. Environmental scanning is an example of an exploitative capability and reactive adaptation is an example of a corrective capability. Ex-post IS capability to exploit or capitalize on information beyond the organizational boundaries through constant scanning of (external) data sources and social networks, and the ability to recover from infliction and ameliorate the impacts of IS failures and mistakes are also critical to information coordination efforts in PSNs. While these pathways have demonstrated their value in improving supply chain flexibility (Gosain, et al., 2005) and outsourcing (Tan & Sia, 2006), the impact on IQ and SQ were still not clear at the start of this research. Moreover, we still needed to shape these pathways to the conditions of PSNs and disaster response, in order to synthesize explicit principles. Accordingly, we come back on examples when we reflect on the third research question (section 9.1.3).

### 9.1.2   Pathways from NCO

When looking to understand NCO one will find a handful of electronic documents, most of them authored by the founders of NCO: Alberts, Garstka and Stein (1999). In a series of four documents, these researchers from the US Department of Defense have stressed the importance of sharing information more swiftly and intelligently in military networks. Their work does not provide a set of propositions or hypothesis related to NCO. Instead, NCO is explained through a set of four 'tenets' emphasizing that real-time information sharing capabilities (through netcentricity) will lead to improved mission effectiveness and efficiency during ad-hoc and hostile military operations (see Chapter 3).

Compared to the first kernel theory (coordination theory), theory on NCO is definitely still in the process of development. If we were to adhere to the strict criteria of Bacharach (1989) on what a theory actually is, NCO would be more a construct than a theory since it lacks clear propositions and hypothesizes. In a latter publication, Alberts and Hayes (2005) support our observation by stating "we may agree that moving to a more network-centric organization is required, but the specifics in terms of new approaches to command and control, organization, doc-

trine, processes, education, training, and even the capabilities we require have yet to be developed adequately" (p.1). As a result, NCO does not yet provide many pathways for assuring IQ and SQ. Nevertheless, including this kernel theory in our research next to coordination theory was not by accident. IS architects and policy makers in PSNs are increasingly mentioning NCO as means of improving disaster management on various levels. Even though there was no scientific evidence on the merits and limitations NCO in PSNs, stakeholders in this domain seemed to be set on introducing it. One explanation for the high level of empirical enthusiasm may lie in the fact that NCO focuses on empowering individuals (i.e., soldiers). Since coordination theory focuses more on managing the interaction between individuals, we viewed NCO as a necessary and complementary kernel theory that we could include in our knowledge base. Acting both as an empirical driver (interests of stakeholders) and a theoretical driver (scarce scientific research), we decided to include NCO as a kernel theory in our research. The existing literature on NCO led to three pathways for assuring IQ and SQ.

The first pathway we drew from the NCO literature is self-synchronization. Self-synchronization has been present in NCO literature since Cebrowski and Gartska (1998) introduced the construct in their seminal article "Network-Centric Warfare: Its Origin and Future." Alberts, Gartska, and Stein (1999) use this term to describe the operating of entities in the absence of traditional hierarchical mechanisms for command and control. According to the tenets of NCO (see Chapter 3), self-synchronization is the link between shared situational awareness and mission effectiveness. In a later publication, Alberts and Hayes (2007) suggest that "self-synchronization leads to dramatic increases in both force agility and effectiveness" (p. 2). Often, self-synchronization is associated with visions of modern warfare in which individual soldiers are equipped with advanced digital headpieces.

Drawing on its initial description in the literature, we have developed a more PSN specific understanding of what self-synchronization means for relief workers and what it could mean for assuring IQ and SQ. Firstly, we do not associate any specific technical features with this pathway. Instead, we focused on unlocking the potential of allowing every relief worker in the PSN to have access to the same information in the same format. Secondly, we considered self-synchronization as a way of empowering the individual relief worker in their need to directly collect, use, update and distribute information anytime and anywhere in the PSN. Our understanding of this pathway rests firmly upon the idea that subordinates have the most up-to-date, accurate, relevant and correct local information, and if they understand the goals (commander's intent) and plans (orders) of an operation, they can produce results superior to the centrally and hierarchically coordinated organization.

The second pathway we drew from the NCO literature is reachback. While self-synchronization refers to abilities of the individual, reachback is associated with technology and is defined as the ability to electronically exploit organic and non-organic resources, capabilities and expertise, which by design are not located in the theater (Neal, 2000). In general, reachback refers to a situation where resources, capabilities and expertise are at a physical distance from the area of interest, supporting the people in the area to perform their tasks. This pathway rests firmly upon the idea that higher headquarters enjoy larger staffs and larger reservoirs of knowledge, experience, and information management capabilities. This pathway suggests that the individual soldier (relief worker), should have access to all information sources in the network, including experts and external (nonmili-

tary) data bases without the mediation of other individuals (i.e., commanders and emergency control rooms). In this way, reachback is a prerequisite for self-synchronization. Given the advancement in information technologies (higher connectivity at lower cost) reachback is becoming easier to implement.

However, from a socio-technical perspective, we consider reachback as a pathway that goes beyond the implementation of technology alone. Following Custer (2003), reachback also raises questions regarding information access levels, sharing policies, and dissemination of sometimes security sensitive information in a network of agencies. This means that we need to be careful in selecting roles that that have full reachback. Moreover, since disasters are low frequency events, the extent of reachback may need to be regulated to minimize the changes of improper use. This strengthened our view that reachback is not only a capability, but can also be a strategic choice to accomplish the goals of a PSN. As such, we have extended the understanding of reachback from a technical capability (no reachback versus full reachback) to a strategic capability (different levels of reachback for different roles in different situations) requiring cautions implementation.

The third pathway we drew from the NCO literature is information pooling. Information pooling is not a new idea and has been coined by scholars in the area of Social Phycology and group decision support in the early eighties (Stasser & Titus, 1985). In the later publications on NCO, this pathway for sharing information from various human and data sources in teams has regained attention. Task-related information known by all members of a multi-agency disaster response is termed shared information, while information held only by one or few team members is considered unshared. Both types of information play important roles in team decision-making: e.g., shared or redundant knowledge may help establish a common situational picture and allow for swift decision-making. The collection of task-relevant information known by every member is termed the pool and thus information pooling is the process of creating and enlarging the pool of shared information that is developed and maintained through group discussion. Information sampling is the process by which team members introduce task related information into a discussion by recalling and mentioning it. One of the important factors that give a team of relief workers an advantage over individual relief workers is the amount and diversity of relevant information held by the team due to its members' differing roles, responsibilities, training and experience. The team therefore is more likely to make informed and high quality decisions. However, in order to utilize their informational resources, team members must discuss and exchange them. Based on literature, we knew that when following this pathway, the categorization of information in the pool in accordance with the preferences of the various relief workers in diverse, cross-functional, or distributed teams would be a major obstacle. We return on how we addressed this challenge in section 10.2.

Concluding, the answer to question 1b (which pathways are provided in coordination theory and netcentric operations theory for assuring IQ and SQ in public safety networks?) includes the seven pathways which we have outlined above. In hindsight, our first hunch did pay off. Drawing on these pathways, we had enough means to enter the field studies and synthesize principles for IQ and SQ assurance. Yet, having surfaced four pathways from coordination theory and three pathways from NCO, we could dwell on the question whether or not more pathways can be found in these theories. For coordination theory the answer would be yes, while for NCO we belief to have surfaced its main pathways. Compared to NCO, coordination

theory covers a wider range of constructs, variables and prescriptions. Given the massive body of publications on coordination theory and its many applications is various research areas, one could conclude that this theory still holds more potential pathways. An example of such a pathway that we have left unexplored is event-driven coordination (Overbeek, Klievink, & Janssen, 2009). Event-driven coordination architectures hold the promise to supplement the netcentric information orchestration (section 9.1.3) through further decentralization of intelligence to orchestrate information across a network of public agencies, without compromising the individual agencies' autonomy. As such, we consider this an avenue for further research. Section 9.4 presents some other avenues for further research.

## 9.2 Research question 2: demystifying information system architectures in PSNs

A considerable part of this research project took place outside the walls of the University. We considered this fun and necessary: fun because it allowed us to observe relief workers in action, necessary because of the 'mystification' of IS architectures in PSNs. While the majority of literature underlines the complexity of disaster response processes and systems, compounded by the unpredictability of information needs and roles, literature provides brief descriptions of such IS architectures. Such brief descriptions lead to the mystification of IS architectures for disaster response. Since there are few contributions available on the design of IS for disaster response (with the exeptions of Kapucu, 2006; Meissner, Luckenbach, Risse, Kirste, & Kirchner, 2002; Turoff, et al., 2004) we decided to conduct field studies. Chapter 2 presents three other reasons for choosing field studies over other data collection methods. The field studies included observing multi-agency disaster response exercises and surveying participating relief workers on the experienced IQ and SQ. In addition, we also tried to capitalize on the design experience of the IS architects by means of interviews. We designed the field studies to answer three sub-questions.

The first sub-question (2a) asked *how do multi-agency teams manage information during disaster response in practice?* Answering this question required us to study various configurations of IS architectures in practice. We sought for answers by triangulating observational data, informal talks with relief workers during training exercises and discussions with exercise organizers before and after training exercises. We formulated the second sub-question (2b) as *considering the various information system architectures in practice, which levels of IQ and SQ do these architectures assure for relief workers during disaster response?* We asked ourselves this question because we wanted to know what kind of impact an particular IS architecture has on the level of IQ and SQ for relief workers. We answered this question using surveys. The survey questions included IQ and SQ items that were tested in previous studies (see Lee et al., 2002). The third and final sub-question (2c) asked *what are the existing best practices of information system architects for assuring IQ and SQ?* This question was asked because we were convinced that IS architects not only have a better understanding of existing IS architectures than we did, but also that they would be the best judges of the pathways we had derived from literature. We investigated this question using semi-structured interviews with experienced IS architects. .Criteria for selecting the architects can be found in Chapter 2. We discuss the findings for each of the sub questions in the following sub-sections.

### 9.2.1 Question 2a: how do multi-agency teams manage information in PSNs?

Based on the field study criteria (e.g., GRIP > 1, different IT applications and roles) discussed in Chapter 2, we decided to include the PSNs in Rotterdam-Rijnmond, Gelderland and Delfland as field study cases. Each of these cases included different IS architectures used for information management during disaster response. We observed 22 training exercises (18 in Rotterdam, 3 in Gelderland and 1 in Delfland), including six initial exercises observed in the winter of 2006, which we used to fine-tune our data collection instruments. We observed these exercises using a predefined observation protocol crafted for studying the information management process, roles, IT applications and IQ and SQ dimensions.

In Rotterdam, multi-agency information management took place using a single IT application. The Rotterdam-Rijnmond region is regarded as one of the 'front runners' when it comes to the development and adoption of innovative IT solutions for safety and security. One of the reasons for this position is the fact that this region hosts one of the largest Seaports in the World, making this region highly prone to disasters. When we started the first series of observations in the winter of 2006, Multi-Team was the main ICT application for inter-agency and inter-echelon information management. This tool allowed teams to share information, in the form of electronic situation reports between the tactical and strategic echelons and the collocated emergency control room. Situation reports were electronic forms containing predefined input fields such as location, weather conditions, hazards, casualties and actions.

During the second series of observations in the winter of 2007, trainers had replaced Multi-Team with CEDRIC (version 1.0). Similar to its predecessor, CEDRIC is based on a thin (client-server) architecture. While the main functionality of this IT application was again to enable the generation and sharing of situational reports, this application also included other functionalities such a emailing, chatting and a phone directory. Moreover, there were ongoing discussions on expanding the functionalities provided in CEDRIC, for instance by including port charts, maps and navigation services. A main hurdle at the time was the relatively low internet connection bandwidth provided by the wireless UMTS connection. Alongside the introduction of CEDRIC, trainers introduced the role of 'information manager' as operator of CEDRIC in the various teams. The role of the information manager includes two simple tasks: (1) generate a situation report during team meetings and (2) send the situation report to the other teams (i.e., COPI, ROT, GVS). Immediately, this decomposition already struck us as insufficient in terms of assuring IQ and SQ. Instead of acting as a boundary spanner, the IM acted as a note taker. It was here that we came to understand the importance of situation reports during multi-agency disaster response. Teams could use situation reports for synchronizing the level of situational awareness between the various multi-agency teams. Yet, the way in which these 'boundary spanning objects' were used in practice, led us to conclude that they do not assure information symmetry across teams. Instead, since teams did not share the situation reports in real-time, they usually contained outdated information. Having experienced this, relief workers did not regularly consult, situation reports, the information manager and CEDRIC, even though these were essential elements of the IS architecture. We found that the information manager role was unable to meet the changing information needs of team members or other individuals in the network beyond the information in-

putted in the consecutive situation reports. As such, we consider this role very basic with no capabilities of assuring IQ and SQ.

As second field study, we observed multi-agency information management in three cross-border training exercises in Gelderland. These exercises included relief workers from the Netherlands and Germany and focused on training the cross-border response to major floods. In Gelderland, information was managed using four different IT-applications FLIWAS, CSS, FloodAtlas and ARCmap. Such a heterogeneous IS architecture is considered to be the common practice in most of the PSNs in the Netherlands. Each of these applications provided a specialized and evolved set of functionalities (i.e., geographic data plotting, flood simulation and message exchange). Relief workers also used these applications in the multi-agency teams on the tactical and strategic level of response. While some of the functionalities across the applications were redundant (e.g., area maps and message exchange), the relief agencies preferred to keep using the four applications rather than one single or integrated application. Next to these four IT applications, we also observed two different roles that were active in inter-agency and inter-echelon information management. Observed roles included the information manager and plotter. In this case, the information manager role was similar to the one we observed in Rotterdam. What was different from Rotterdam was the lower level of reliance on the situation reports in Microsoft Groove. Using this application, teams were able to create a shared workspace allowing information managers to distribute files and folders throughout the PSN. However, many of the agencies did not use this application, partly because it does not support all the specific functionalities required by the agencies. Instead of focusing on a single situation report, relief workers focused on the information that was coming in via the application that they were using. However, since these applications are neither integrated nor interoperable, we observed several instances of inconsistent information sharing. Yet, this did not mean that relief workers were aware of the fact that their comrades from other agencies had different/inconsistent information.

The final field study was conducted at the Hoogheemraadschap Delfland where multi-departmental information flows were managed using whiteboards, so without any software or electronic applications. Here we need to state that this field study was less comprehensive than the previous two in terms of number of exercises and participants. Moreover, this field study focused on intra-agency disaster information management, whereas the other two field studies focused on information management between multiple agencies. The water management agency in Delfland uses whiteboards for inter-departmental and inter-echelon information management. In this field study, teams shared information using five large whiteboards. While the water management agency is considering electronic means for information management during disasters (e.g., FLIWAS), this agency still uses whiteboards as a mean to convey information within their organization. The idea is that the whiteboards retain the most relevant and up-to-date information to all relief workers. An information coordinator role is used to manage the information on the whiteboards. The information coordinator was the only role allowed to put or remove information on the whiteboards (using markers). In contrast to the role of the informer manager in Rotterdam and Gelderland, the role of information coordinator included a broader range of tasks. The information coordinator was not only responsible for pulling information from the various departments, but also for posting and updating this information on the whiteboards. As elaborated in section

4.5.5, we observed that this role was quite busy during the disaster, and was less able to update information on the whiteboards as the disaster situation progressed. This resulted in several examples of outdated information. Another problem with this approach was that the handwriting of the information coordinator was not clear to everyone. This resulted in situations where relief workers were trying decrypt the handwriting of the busy information coordinator.

Considering the qualitative field study findings, our answer to question 2a (*how is information managed in public safety networks during disaster response?*) is that information is managed using a mix of both IT and non-IT applications, boundary objects (e.g, situation reports) and roles (e.g., information manager, coordinator and plotter). Therefore, we conclude that various types of IS architectures exist. Common to the investigated IS architectures is the focus on top-down (vertical) flow of information between the echelons of a specific agency. This form of information management firmly rest on the hierarchical authority structure of the individual agencies. The only time information is formally shared horizontally (between agencies) is during the tactical and strategic echelon team meetings. We found that the trainers and agencies in the studied PSNs are looking for 'one best' way of coordinating information. In Gelderland, trainers are still in the process of evaluating the use of the four different IT applications, whereas the PSN in Rotterdam has decided to work with a single IT-application. In both Rotterdam and Gelderland we recorded instances of 'reinventing the wheel', indicating that information which was already available somewhere else in the network was requested and searched for again. In contrast to the whiteboards used in Delfland, the ISs in the other field studies did not have the ability to retain or buffer information. In the examined PSNs, stakeholders are still exploring the boundary-spanning pathway, meaning that the roles of the information manager and information coordinator are still in the process of refinement. Compared to the whiteboards, the IT applications used in Rotterdam and Gelderland enable the operators to act as boundary spanners, albeit with very few capabilities to assure the IQ and SQ. The three field studies show the lack of empowerment of relief workers, especially the ones that should act as boundary spanners. The information manager role (Rotterdam and Gelderland cases) consists of far too simple task and is ill supported when it comes to reach-back and synchronization capabilities. On the other hand, the information coordinator role (Delfland case) is too complex, demanding far too much time from a single person. Therefore, we conclude that the tendency to centralize information and information related roles, compounded by the low level of empowerment (i.e., through reachback and self-synchronization) has negative impacts on the IQ and SQ for relief workers. Another important conclusion we came to in this phase was that relief workers mainly focused on their individual information needs. Instead of sharing, relief workers focused on pulling information that they thought was relevant for their own tasks, without any consideration for the information needs on a network level. Examples included police officers not sharing information on the victims that they have rescued with the fire brigade and ambulatory services not sharing information about victims that have reported smelling some kind of gas to firefighters. As relief workers are trained on completing their own set of processes during a disaster, they do not reflect on the information that is not directly important to their tasks, even though this information could be of critical importance to the relief workers of other agencies.

### 9.2.2 Question 2b: which levels of IQ and SQ do existing information systems assure?

We investigated question 2b using surveys. After the training exercises in Rotterdam-Rijnmond, Gelderland and Delfland, we requested relief workers to indicate the levels of IQ and SQ during the exercise. Besides some background questions, the surveys mainly contained propositions based on tested questionnaire items (Lee, et al., 2002). Using a standard 7-point Likert-scale respondents could indicate to what extent they agreed with the propositions (1= totally disagree and 7= totally agree). In total, we received 153 completed surveys (83 from Rotterdam, 46 from Gelderland and 24 from Delfland). We found that each of the investigated IS architectures leverage different levels of IQ and SQ for relief workers.

We collected the first set of quantitative data from the Rotterdam-Rijnmond field study. The single IT application based IS architecture leveraged moderate (score ≈ 4) scores for IQ-timeliness (4,32), IQ-completeness (4,84), IQ-correctness (4,82) and IQ-consistency (4,93). With an average score of 5,14 and SD of 0,99 the IQ-relevancy dimension stands out, indicating that most relief workers found the information shared with them to be relevant for their tasks. The relatively high standard deviation (SD) for IQ-consistency (SD=1,54) hints to some disagreement on whether the information shared was consistent or not. In addition, the level of IQ-information overload was low (3,15), indicating that the relief workers usually did not receive too much information. When considering the SQ dimensions, this IS architecture leveraged moderate scores for SQ-accessibility (4,72) and SQ-reliability (4,57), but low scores for SQ-response time (3,53), SQ-satisfaction (3,93) and SQ-flexibility (3,39). This not only indicates that the relief workers were not very satisfied with the IS architecture used, but also that this IS architecture resulted in long waiting times for information and adapted poorly to the changed information needs. Note that the standard deviations for SQ-response time (SD=1,84), SQ-satisfaction (SD=1,80) and SQ-flexibility (SD=2,07) were relatively high, indicating some spread and disagreement on the perceived score for these dimensions.

We collected the second set of quantitative data from the Gelderland field study. Trainers allowed us to administer short paper surveys directly after one of the training exercises. The paper-based survey was a shortened version of the online survey administered in Rotterdam-Rijnmond. Due to time restrictions imposed by the trainers, we were only able to use one item per IQ and SQ dimension (instead of 3 items such as in the Rotterdam-Rijnmond case). The multi-IT application based IS architecture in Gelderland leveraged moderate scores for IQ-timeliness (4,43), IQ-completeness (4,61), IQ-correctness (4,80) and IQ-consistency (4,48). With an average score of 5,37 and moderate SD (1,06), the IQ-relevancy dimension stands out. Another interesting number from the data analysis is the average score of 4,24 for IQ-information overload, which when considered in relation to the high SD for this dimension (SD=1,85) leads us to conclude that there were some issues regarding the amount of information relief workers needed to deal with. When considering the SQ dimensions, the multi-IT application based IS architecture leveraged moderate scores for SQ-accessibility (4,37), SQ-reliability (4,87), SQ-timeliness (4,24) and SQ-satisfaction (4,72). The lowest average score was attributed to SQ-flexibility (3,43) indicating that the four IT applications adapted poorly to the changed information needs. When we look at the standard deviations for SQ-response time (SD=1,77), SQ-satisfaction (SD=1,60) and SQ-

flexibility (SD=1,75) we can conclude that there is some spread and disagreement on the perceived levels for these SQ dimensions. An additional SQ-construct we used in this field study was SQ-usefulness. This construct operationalized in a single item (the IT was very useful for completing my tasks) received a high average score from the participants (5,13). One explanation for this is that the various IT applications in Gelderland were more tailored to the tasks and information needs of the different relief agencies.

We collected the third set of quantitative data from the Delfland field study. Similar to the Gelderland field study, trainers allowed us to administer paper surveys immediately after a training exercise. Since these surveys were subject to less strict constraints than in Gelderland, we decided to use three items per construct similar to the Rotterdam-Rijnmond questionnaires. The whiteboard centered IS architecture in Delfland leveraged moderate scores for IQ-timeliness (4,53), IQ-completeness (4,06), and IQ-consistency (4,71). With an average score of 5,22 the IQ-relevancy dimension stands out. In addition, IQ-correctness also received a relatively high average score (5,00). Another interesting number from the data analysis is the average score of 2,79 for IQ-information overload, which when considered together with the moderate SD for this dimension (1,50) leads us to conclude that overall, there were no major issues regarding the amount of information relief workers needed to deal with. When considering the SQ dimensions, this IS architecture leveraged moderate scores for SQ-satisfaction (4,41) and SQ-ease of use (4,74). We have included an item on SQ-ease of use due to a request of the exercise organizers whom wanted to know how easy to use the whiteboards were. The data analysis revealed lower average scores for SQ-accessibility (3,93), SQ-reliability (3,96) and SQ-timeliness (3,35), indicating that relief workers using the whiteboard based IS architecture had some issues with getting rapid access to information. Another interesting average score is that of IS-digitalization. We added this dimension as a way to measure the preference to digitalize the existing whiteboards. Based on the average score of 5,48 and the standard deviation of 1,69 we can conclude that the majority of relief workers would prefer to share information via electronic whiteboards.

It was not our initial intention to compare the average scores for the measured IQ and SQ across the field studies, mainly because the characteristics the field studies (e.g., type of IT used, scenarios trained and training exercise design) were very different. Moreover, we were also restricted in the number of survey constructs and items we could use, further complicating cross-field study comparability. Acknowledging of these constraints, we thought it would be interesting to compare the average scores for the measured IQ and SQ across the field studies. First, the quantitative data allows us to conclude the IT supported IS architectures (Rotterdam and Gelderland) outperform the whiteboard based IS architecture on IQ-completeness, SQ-timeliness and SQ-accessibility. This being the case, the whiteboards did not leverage unacceptable levels of IQ-relevancy and IQ-correctness, and even scored better on IQ-information overload. We even found it to be somewhat contra-intuitive that the average scores for IQ-correctness (5,00) and the IQ-relevancy (5,22) of the information shared via the whiteboards in Gelderland was higher compared to the Rotterdam and Gelderland field average scores. One explanation for this may be that the information posted on the whiteboards were selected on its relevancy and filtered on its correctness by the information coordinator.

Another interesting finding is that the perceived level of IQ-information overload was lower (2,79) when compared to the Rotterdam-Rijnmond and Gelderland field studies. The information on the whiteboards was also rated as fairly consistent (4,71). This is not strange when considering that the information coordinator was the only person allowed to post and remove information from the whiteboards. On the other hand, SQ-timeliness (3,35) and SQ-accessibility (3,93) scored lower in Delfland than in the other two field studies. We also found that IQ-consistency was slightly higher when using one single and integrated IT application (Rotterdam) and whiteboards (Delfland) than when using multiple IT applications (Gelderland). The use of multiple IT applications also had a negative effect on IQ-overload (higher), something that can be expected when team members get (sometimes redundant) information from multiple sources at the same time.

Interesting is that the scores for the IQ-relevancy and IQ-correctness were higher for Gelderland than the scores in Rotterdam. We attribute this to the use of more specialized software applications that assure higher IQ-relevancy and IQ-correctness than information management using less specialized software (i.e., CEDRIC). Since the Analysis of Variance indicates that there is no strong statistically significant difference between the Rotterdam and Gelderland scores for IQ-relevancy and IQ-accuracy, we cannot defend this argument based on the collected data. Noteworthy is that the relief workers in Gelderland did experience a statistically significant higher level of IQ-information overload (4,24) than the relief workers in Rotterdam (3,15). The reason for this can be attributed to several factors, including the presentation of information. In CEDRIC, information was presented in a standardized and easy to navigate screen, whereas the information presented in the Gelderland applications was less standardized. Based on this generic comparison, we can conclude that the use whiteboards for information management within a single agency assure moderate levels of correct, consistent and relevant information, yet does not provide information quickly enough.

### 9.2.3 Question 2c: what are the existing best practices of information system architects for assuring IQ and SQ?

We investigated sub-question 2c using sixteen semi-structured interviews with IS architects. The results indicate that there are no commonly shared principles in use. While NCO and service oriented architectures (SOA) are surfaced as future 'good' practices, the current practices converge on assuring SQ-interoperability and SQ-response. The interviewees were senior level IS architects from various relief agencies in the Netherlands. The criteria for selecting these interviewees are discussed in chapter 2.5. In retrospect, the interviews with the sixteen IS architects discussed in Chapter 5 formed a valuable part of our research. Not only did the interviews allow us to better understand the design of existing IS architectures, they also provided insights on the occurrence of IQ and SQ issues and the existing means of dealing with these issues. In addition to understanding existing IS architectures, the interviewees helped us to further explore and shape the seven pathways provided in NCO and Coordination theory before entering the design cycle and evaluation cycle of this research.

While not agreeing on the importance of all the presented dimensions, the interviewees acknowledged the occurrence of IQ and SQ issues in current PSNs. Related to question 2c, the interviewees agreed that assuring IQ is a major challenge that needs to be addressed collectively. However, most of the interviewees

declared that they are currently focusing on assuring SQ, particularly focusing on improving the technical interoperability of existing IT applications. This means that the current efforts of policy makers and IS architects in several PSNs are concentrated on developing IT-applications that provide specific functionalities (e.g., geographic maps and hazards zone indication) and on making existing applications more interoperable (e.g., using middleware and web services). As such, assuring SQ is the going concern, while assuring IQ might be the focus in five or ten years. While one of the reasons for neglecting IQ lies in its subjectivity, the main reason for the focus on SQ according to the interviewees is the increased pressure of the national government on relief agencies, requiring them to collaborate on a regional level (see the discussion on the development of Safety Regions in Chapter 4.1). We found that the current IT landscapes in PSN are fragmented and can best be described as a unstructured combination of IT 'silos', where each silo is originally designed to serve the internal and predefined (routine) information needs of the own agency.

The interviewees revealed the rise of two, to some extent opposing, developments that may become shared best practices in PSNs. First is the increasingly mandatory introduction of CEDRIC, a centralized IT application that BZK (Ministry of Internal Affairs and Kingdom Relations) often associates with NCO. Similar to our field study observations, we see a tendency to centralize information, information related functions and responsibilities. We are not sure where this tendency comes from, an explanation may be that agencies prefer to have control over the developed IT. While most of the architects do not view CEDRIC as the only way to materialize NCO, they argue that NCO can lead to improved information sharing in terms of speed and connectivity. The debate here is whether CEDRIC enables the true intentions of NCO or not, being network wide reachback, self-synchronization and information pooling. The second development pointed out by the interviewees is the increasing adoption of SOA as a way of organizing future IS architectures. Suggested advantages of using SOA include modularity, flexibility and most important from a SQ perspective, technical interoperability. Developing SOA based IS could also enable NCO, but is the opposite direction of adopting CEDRIC. As one of the technical means for enabling orchestration, SOA does not require the destruction of variety through uniformity. Instead, SOA allows for the technical interoperability of various, previously incompatible, applications via standardized message containers (e.g., web services). This is in line with the pathway of orchestration. Since NCO and SOA were opposing developments, the majority of interviewees raised their concerns about the current policies in PSN and the lack of nationally accepted reference architectures or principles for developing IS for disaster response. In the light of these developments, some of the interviewees applauded our research efforts on developing and evaluating design principles, whereas others had mixed feelings about the impact our work would have in this field. These mixed feelings were fuelled by the increasing number of technologies (see section 1.4 for an overview) that are being developed for disaster response, while, in the view of the interviewees, many of these technologies do not resonate with the context of use and processes of relief workers.

Before starting the field studies, we did not know what to expect regarding IS architectures in PSNs, especially since literature on their configuration was scarce. Moreover, previous contributions have to some extent 'mystified' information management in disaster response as a process, claiming that there is no

form of predictability and structure whatsoever. Our field studies help in demystifying IS architectures for disaster response in practice. We found that to some extent, stakeholders could anticipate the information flows and information needs across several types of disasters. The information categories listed in situation reports prove that relief workers are already moving from total unpredictability to a moderate level of anticipation. Perhaps the Pareto rule (also known as the 80%-20% rule) may be an appropriate analogy for this demystification, meaning that 80% of information management during disaster response can be predicted and prepared for (advanced structuring), whereas 20% depend on a too wide range of factors that are impossible to prepare for. To conclude, the reported field studies constitute a crucial part of this research by equipping us with knowledge on IS architectures and current practices for assuring IQ and SQ. The knowledge gained in this cycle was a prerequisite for starting the third cycle of this research that we reflect on next.

## 9.3  Research question 3: netcentric information orchestration as a design theory

Equipped with the knowledge gained from theory and practice, we entered the design cycle of our research. The research question we addressed in this cycle asked *which design principles can we synthesize from the knowledge base and empirical data for assuring IQ and SQ during multi-agency disaster response?* It is in this phase that we aimed to synthesize a design theory for assuring IQ and SQ in PSNs.

We first expected that answering question 3 would only require that we induce principles by integrating the seven pathways provided in the two kernel theories with the knowledge gained from the three field studies. However, this inductive process did not directly result in the set of principles we were aiming for, mainly because we were unable to relate the pathways directly to the IQ or SQ dimensions. We still needed an important stepping-stone before we could synthesize principles. Based on our interviews with the IS architects, we came to the insight that since we were investigating ISs, we first needed to establish the capabilities that were needed to assure the dimensions of IQ and SQ. As such, we first needed to deduce detailed capabilities that would function as stepping-stones towards the induction of more generic principles. Here, capabilities refer to IT-enabled competencies that agencies or multi-agency teams constitute, employ and adapt during disaster response.

In the process of capability deductions, advanced structuring and dynamic adjustment proved to be more than pathways, they also helped in categorizing the capabilities needed in time (before and after a disaster) and nature (offensive and defensive capabilities). Capabilities under the advance-structuring category promote the empowerment of relief workers through information pooling, self-synchronization and reachback capabilities, while diversifying information sources for redundancy and triangulation purposes. On the other hand, capabilities under the dynamic structuring category promote active environmental scanning and information quality feedback by means of validation and rating. When utilizing these capabilities, orchestrators (advancements of the information manager and coordinator roles) are expected to fulfill a spectrum of information coordination roles, including information foragers, boundary spanners, quality monitors, environmental scanners and enrichers (completing information or adding value to information).

Section 6.5 presents the set of ten principles in conjunction with the IQ and SQ dimensions they assure. We have dedicated an entire section (6.2) on the definition, meaning and implications of principles in the context of principle-based design. In short, *principles* are normative and directive guidelines related to one or more architectural components that need to be (re)designed by IS architects in order to achieve one or more network level goals. Here, IQ and SQ are considered as network level goals. Some of the stated principles are more theory driven, while other principles firmly rest on the field study. In accordance with the guidelines for communicating design principles provided by The Open Group Architecture Forum (TOGAF), we elaborate on the pathways each principle rests upon, the rationale behind the principles and the expected implications for the IQ and SQ next. We come back on whether our expectations were satisfied or not in section 10.3.

The *first* design principle is 'maintain a single, continuously updated information pool throughout the PSN'. This principle rests upon two pathways (boundary spanning and information pooling) and is driven by the field study observation that situation reports are powerful, yet ill-designed boundary objects. From the field studies, we found that relief workers needed the ability to dynamically integrate information supply and demand. By proposing the replacement of several, immediately outdated situation reports, we expected that this principle would assure IQ-timeliness, IQ-completeness and SQ-response time.

The *second* design principle is 'maximize feedback on the quality of shared information'. This principle is rooted in our observation that relief workers lacked the capability to validate the quality of the information they had received or collected. We expected that the ability to determine the quality of information, for instance using an information rating capability, would help relief workers to judge whether to use the shared information or not. We expected that this principle would assure IQ-correctness and IQ-reliability.

The *third* design principle is 'maximize the reachback of orchestrators'. This principle is rooted in the NCO reachback pathway and our observation that information managers and coordinators lacked information access capabilities. We expected that the ability to directly access information (without first having to contact the emergency control room) form agency and external (third party) data sources would assure IQ-completeness, SQ-accessibility and SQ-response time.

The *fourth* design principle is 'categorize information as much as possible'. This principle rests mainly upon the observation that relief workers avoid information overload through categorization. This principle is consistent with one of the premises of Turoff et al., (2004) whom also suggest that the ability to (automatically) categorize information would avoid IQ-overload.

The *fifth* design principle is 'notify changes in information as soon as possible'. This principle is rooted in the NCO self-synchronization pathway and the observation that relief workers were often unaware of changes in information objects (i.e., on the direction of the wind or the number of hazards). While someone in the PSN did have information needed, the lack of capabilities to synchronize information objects over the network led to decision-making and action based on incomplete information. We expect that the ability to obtain changes in critical information objects in real-time would assure IQ-timeliness, IQ-correctness, IQ-relevancy and SQ-response time.

The *sixth* design principle is 'provide a single window for all information needs'. This principle is rooted in the observation that the use of several IT-

applications (Gelderland field study) increases information asymmetry between teams and agencies across the PSN. Following the orchestration pathway from co-ordination theory, this principle promotes the re-use of services and functionalities across applications. We expect that the ability to find all relevant information via a one stop shop would assure IQ-timeliness, IQ-completeness, IQ-relevancy and SQ-response time.

The *seventh* design principle is 'retain as much information as possible'. This principle is rooted in the advanced structuring pathway and the observation that much information is lost during disaster response. We expected that the ability to buffer information, view the history of information and re-use information, for instance in libraries, would assure higher IQ-completeness and IQ-relevancy.

The *eighth* design principle is 'dedicate specific resources for environmental scanning'. This principle is rooted in the dynamic adjustment pathway and the observation that relief workers lack the ability to scan the entire PSN and the outside environment for information. Here, we expected that the ability to scan information sources throughout and beyond the PSN (e.g., via Twitter, YouTube) would help orchestrators to find complementary information, thus assuring higher levels of IQ-timeliness, IQ-completeness and SQ-response time.

The *ninth* design principle is 're-use information as much as possible'. This principle is rooted in the observations of repeated information requests and collection efforts during the field studies. Since there is no shared information space or library, relief workers and information managers were often not aware of information already available in the PSN. Consequently, the redundant requests for information consumed the already scarce information management capacity of the information managers and control rooms. As such, we advocate that after initial validation by orchestrators or experts, relief workers re-use information that is available in the PSNs as much as possible.

The *tenth* design principle is 'make the owner of information objects responsible for updating their own information'. This principle is rooted in the observation that an enormous amount of information is shared during a disaster, whereas the responsibility of updating the information is not explicit, resulting in confusion about the timeliness of information. In contrast to making the information manager or coordinator responsible for collecting and maintaining up-to-date information in CEDRIC or MS Groove, we advocate that the source of information should be responsible for updating information in the information pool. Consistent with Hammer (1990), we expected that this principle would assure IQ-timeliness.

In retrospect, we expected at least a dozen principles as outcome of the design cycle, partly because of the smaller number of principles provided in other, smaller studies (Garfein, 1988; Richardson, et al., 1990). While we did not aim for any specific number of principles, at first, ten principles seemed to be too few. Still, after scrutinizing each design principle and pondering on its impact in practice, we belief that this set of ten design principles forms an appropriate answer to the third research question stated above. Stretching the notion of 'design theories' (Gregor & Jones, 2007), we propose the combined set of design principles as a design theory for assuring IQ and SQ in PSNs. We call this design theory '*netcentric information orchestration*' since it rest firmly on the pathways provided in Coordination theory and NCO. The framework is probably more empirically driven, but the insights are consistent with the theoretical arguments in coordination theory (March and Simon, 1958; Gosain et al., 2004) and NCO (Alberts and Hayes, 2006). From this

framework (see section 6.3), netcentric information orchestration can be understood as a network wide, decentralized and distributed way of managing information through empowered information managers with IT enabled capabilities. We discuss the evaluation of this design theory in the next section.

## 9.4 Research question 4: quasi-experimental gaming-simulation

"The proof of the pudding is in the eating." As design science researchers, we firmly believe in this adage. Accordingly, the final cycle in our design science research was the evaluation of the proposed design theory. The question leading this phase asked *to what extent do the proposed design principles assure higher levels of IQ and SQ for relief workers when compared to existing information systems?* It is in this phase that we wanted to evaluate the extent to which the design principles behind netcentric information orchestration assure higher levels of IQ and SQ compared to existing, hierarchy based IS architectures without empowered information managers. The evaluation cycle consisted of two steps: (1) prototyping and (2) quasi-experimental gaming-simulation.

We chose to develop a prototype based on the ten design principles for two reasons. First, the prototype itself would be a proof of technical feasibility: the extent to which we could translate our design principles into a tool for relief workers. Secondly, we would use the prototype, as embodiment of the design theory, when evaluating the proposed design theory. Thanks to our field studies and examination of IT applications for information sharing, we had sufficient knowledge about the environment and setting in which the prototype needed to operate. We called this prototype DIOS, an abbreviation for Disaster Information Orchestration System. We elaborate on the nuts and bolts of this prototype in Chapter 7.

After completing the first version of the DIOS prototype, we were able to start developing gaming-simulation sessions. Since we had gained some experience on training relief workers from the observed training exercises, we decided to employ this knowledge in the form of a gaming-simulation with relief workers. Thanks to our involvements in other research projects beyond the scope of this research (Bharosa, Meijer, Janssen, & Brave, 2010), we had also gained some experience in designing gaming-simulations for evaluation purposes and expected that this method would allow for a more in depth, valid and interactive evaluation of our design theory. As we explained in Chapter 2, gaming-simulations combine traditional forms or role-playing games with quasi-experimentation. While gaming is the main form in which disaster response scenarios are simulated, quasi-experimentation refers to the structure of the gaming session, which in our case was divided in two rounds (with and without our design principles).

Before the evaluation session with professional relief workers, we conducted a pre-test with twenty-four graduate students at the Delft University of Technology. The pretest paid-off, we became aware of one problem in our game design and two problems in the DIOS version 1 prototype. The problem in our game design was that we had too few messages to keep the players focused. Looking back, we thought that a few messages and events would be complex enough to keep the flow of the game going. The pre-test taught us that we needed to have more scenario related events in the form of messages ready. Reflecting on the prototype, the Microsoft Access database we used in DIOS version 1 was unable to handle the number of simultaneous entries during the game. While we were aware of the limited

capacity of such a database, we did not expect that eight orchestrators would already be too much. The MySQL data employed in DIOS version 2 had no problem in dealing with eight simultaneous entries. A second problem with DIOS version 1 was the graphical user interface. According to the students who used the prototype, the hierarchical, wiki-based navigation structure of DIOS version 1 was too complicated and difficult to use. The pre-test revealed that we needed to simplify the user interface even more, and adhering to the sixth principle, minimize the number of screens and views in the prototype. The resulting DIOS version 2 prototype was expected to be more robust and easy to use. After the pre-test with graduate students, we evaluated netcentric information orchestration as design theory using a quasi-experimental gaming-simulation with professional relief workers. Here, 'quasi-experimental' means that the gaming-simulation consisted of two rounds, one with DIOS and one without. The main difference between both rounds was the use of DIOS for information management all other factors were kept constant in order to avoid other causal interferences. This simple, yet most commonly applied way of quasi-experimentation allowed us to collect data on the effects of DIOS on IQ and SQ. In order to collect qualitative data, the gaming-simulation sessions were observed using observation protocols and were recorded on video. Quantitative data on IQ and SQ was collected using paper based surveys.

As with any form of experimentation, we had some expectations of the results. These expectations surfaced from the field study observations and the findings from the pre-test with students. First, we expected that the design principles would not assure all of the IQ and SQ dimensions and that some trade-offs would emerge from the evaluation cycle. For instance, while we expected that rating the quality of information before sharing (design principle 2) would assure higher levels of IQ-correctness and IQ-relevancy, we were uncertain about the effects of this principle on the IQ-completeness and SQ-response time. We also expected that DIOS would perform well and would improve IQ timeliness and SQ-response time, but would become the main goal of the evaluation (from the perspective of the participants) instead of being just a 'tool' that materialized the design principles. Moreover, we expected that the professionals would be very satisfied with netcentric information orchestration. In addition, we expected that there would be some concerns about the scenarios of the gaming-simulation. Finally, considering the warnings issued by Stanovich (2006), we expected that netcentric information orchestration would have some 'side-effects' since the participating relief workers were not yet adequately trained in coordinating information in this way.

Given these expectations, let us first reflect on the quantitative data collected during the gaming-simulation with professional relief workers. Similar to the field studies, we employed a survey consisting of propositions on a selection of IQ and SQ variables. In order to assure construct reliability, we used the three items per construct rule. While adherence to this rule made our paper based survey longer, we did not expect any complaints from the participants since they were aware of the goal of the gaming session. We did however still receive a few complaints, but managed to circumvent these by underlining the importance of the survey data for our research. In the end, we received and analyzed twenty-two surveys for each round. Using SPSS we analyzed the data and calculated average scores and standard deviations for all the IQ and SQ dimensions. When comparing the IQ dimensions over round 1 (without DIOS) and round 2 (with DIOS), the data shows improvements in IQ-timeliness (3,80 versus 4.29), IQ-correctness (4.33 versus 5.00),

IQ-completeness (3.46 versus 3,71), IQ-relevancy (3.71 versus 3.78) and IQ-format (2.55 versus 3.70). The only IQ dimension that was lower in round 2 than in round 1 was IQ-consistency (4.63 versus 4.00). When comparing the SQ dimensions over round 1 and round 2, the data shows improvements in SQ-accessibility (2.47 versus 4.53), SQ-satisfaction (2.53 versus 3.41), SQ-response time (2.15 versus 3.75), SQ-information sharing support (2.98 versus 4.15), SQ-notification (2.42 versus 3.89) and SQ-feedback (4.20 versus 4.78). When we consider the quantitative data, most IQ and SQ scores indicated by the relief workers are higher for netcentric information orchestration (round 2) than hierarchical information coordination (round 1). As expected, netcentric information orchestration resulted in more timely information at lower response times. While the compared average scores indicate that netcentric information orchestration improves most of the measured IQ and SQ dimensions, a test of the statistical significance of the apparent differences between requires us to interpret the quantitative results more carefully. When adhering to such strict rules for statistical significance, we can say that regarding the IQ, netcentric information orchestration assured higher levels of IQ-correctness and IQ-timeliness. Regarding the SQ, netcentric information orchestration assured higher levels of SQ-accessibility and SQ-response time (indicating a lower response time).

Having discussed the quantitative data, we proceed by reflecting on the extent to which each principle assured higher levels of IQ or SQ when comparing the results of both rounds. Here we mean both qualitative results (gained from observation notes, video recordings and debriefing sessions) and quantitative results (gained from surveys). As such, this reflection process triangulates the data collected using the different instruments. The *first* principle (maintain a single, continuously updated information pool throughout the PSN) proved to have the most impact on the IQ and SQ. The result of this principle is that everyone possessed the most up-to-date and complete situation report, partially accounting for the higher IQ-timeliness and IQ-completeness in round 2. The relief workers were able to share a wider range of information more quickly and over the same platform. Sharing information in this way almost immediately revealed inconsistencies in the information shared between teams. This may be the main reason why IQ-consistency was actually lower in round 2. When information is coordinated hierarchically, it is more difficult to spot inconsistent information from the position of the individual relief worker. Another noteworthy finding regarding this principle is the lack of responses to the information requests in DIOS. Everyone saw the information requests, and yet we observed that most of the requests did not attract a response. One explanation for this may be the tendency of the teams to move on with decision-making instead of replying to information request. We also observed situations in which relief workers made decisions outside their mandate, just because they had the ability to do so in DIOS. Literature (see Stanovich, 2006) has already warned us for this type of 'renegade freelancing'. With the high level of empowerment achieved by using DIOS comes the concern that subordinates will step out of their tasks description and may conflict with the intentions of commanders. We argue that if the full potential of network based coordination solutions is to be utilized, stakeholders need to address this issue of freelancing. Further research may want to consider the development of an 'overruling' functionality or rules for dealing with information posted by relief workers that do not have the authority to decide on that particular type of information.

The *second* design principle (maximize feedback on the quality of shared information) increased the speed in which relief workers navigated through the information shared in DIOS. Borrowing the idea of information rating from open source networks such as Wikipedia and Google Android Market, we have materialized this design principle as a rating functionality in the DIOS prototype. During the gaming-simulation, we requested the participants to rate information that they or others have shared as much as possible. For all the participants, it was the first time that they saw how relief workers from other agencies reacted to the information they shared through feedback or information requests. This principle helped relief workers in determining the reliability and correctness of information, probably leading to the high average score for SQ-feedback. The final discussion round with the relief workers revealed that relief workers were often unaware of the impact rating had on the information management process and that this was something that was not trained in current practices. While acknowledging the potential of this principle, some of the participants questioned the effects of information ratings on the information management and decision-making process. Questions from participants included "what do we do with information that is rated as unreliable but may still be very important in terms of the impact that it may have on the entire disaster response process? The example of information (there may be some explosive chemicals stored nearby a fire on a university campus) that was first rated as unreliable, created some hesitation amongst some of the relief workers on acting upon receiving this information. Questions from participants such as "is it an expert rating?" invite further research on the type of rating that relief workers prefer and the effects the ratings may have on decision-making and action in PSNs. As such, further research needs to determine the right scales and rating procedures.

The *third* design principle (maximize the reachback of orchestrators) proved to be more difficult to maintain in the gaming-simulation than we first expected. The increase in SQ-accessibility in the quantitative data indicates that the relief workers understood that netcentric information orchestration provided more reachback capabilities to the teams. Even though we presented and explained the enhanced reachback capabilities of the orchestrator before round 2, relief workers seemed to hold on to the initial role of the information manager (as played in round 1), and infrequently utilized the advanced reachback capabilities of the orchestrators. This means that information from external sources such as Google, Twitter, Wikipedia and the University Website was often not consulted. While to some degree this issue can be remedied through more training with DIOS, we argue that the person fulfilling the role of an orchestrator should be more proactive in advertising the reachback capabilities available within the team. Nevertheless, we still expect that after more training, this principle will help assuring IQ-timeliness, SQ-accessibility and SQ-response time.

The *fourth* design principle (categorize information as much as possible) proved to be a mixed blessing when it comes to assuring IQ and SQ. The format in which information was shared (IQ-format) was rated higher for round 2 than for round 1, indicating some improvement in how the information was presented to the relief workers. Still, we observed that some of the relief workers quickly noticed the information categories in DIOS, while others had more difficulty in finding what they were looking for. This did not necessarily mean that there was any IQ under- or overload (IQ-amount). Note that we did not include survey questions on IQ-amount, mainly because we did not find any evidence for information overload or

under load in the field study data. Even though the categorization we used in DIOS was rooted in the categories of information we found in the situation reports from our field studies, the debriefing session after round 2 showed that our categorization still did not meet the expectations and needs of all the different types of agencies and relief workers. Therefore, we conclude that more research is required on finding and filtering the right information categories that cater the need of a multi-agency team. We expect that only then, this principle will significantly assure higher IQ-amount and SQ-ease of use.

The *fifth* design principle (notify changes in information as soon as possible) proved to have a positive impact on SQ-notification. Changes, for instance in the near real-time weather conditions were displayed in the DIOS dashboard section. We had decided to implement this principle in a relatively modest way, meaning that the changes lacked 'flashy' and eye-catching graphics and colors. This was a conscious decision; we expected that too much graphics would unnecessarily disturb the team meeting and decision-making process. Acknowledging that 'too subtle' change notifications could miss the entire purpose of this principle, our observations show that our choice was justified. An important condition for the success of this principle is that the relief workers trust the IT application on portraying the latest information.

The *sixth* design principle (provide a single window for all information needs) proved to assure higher levels for IQ-timeliness and SQ-accessibility. Some of the participants indicated that they were used to employing multiple applications for collecting the information they needed, but the use of a single window was definitely more convenient and time saving. However, we also observed some complaints in dealing with irrelevant information in a single window and heard requests for more agency and role specific information displays. As expected, respondents often commented on the presentation layer of DIOS as if it was the goal of the evaluation session, and commented on its color, user interface and other, non-principle related features. This may partly explain the relatively low increase in SQ-satisfaction compared to round 1. Accordingly, we often had to request them to treat DIOS as prototype and comment on the underlying principles. Similar to the previous principle, this principle can also have a negative impact on assuring IQ-relevancy, if not implemented correctly.

The *seventh* design principle (retain as much information as possible) did not have the high impact on the IQ dimensions we expected before the gaming-simulation. Only three of the observers noted instances in which relief workers consulted the 'older' information automatically stored in the dynamic library in DIOS. Here, older does not necessarily mean outdated, information that was not relevant at t=1 can still be up-to-date at t=3 (assuming the information has become relevant at t=3). In retrospect, perhaps the relatively short duration of the disaster scenario we used in the gaming-simulation did not require relief workers to employ the library in DIOS. In practice, disaster response can take several hours and even days, increasing the likelihood of situations in which relief workers need to consult information libraries. Moreover, in contrast to some of the exercises in the Rotterdam case and the Gelderland case, there was no need for 'hand-overs' between consecutive teams of relief workers. We expect that when sharing information during a real disaster, with hand-overs between shifts of relief workers, would be a better test for this principle than our gaming-simulation.

The *eighth* design principle (dedicate specific resources for environmental scanning) helped teams in getting information beyond their traditional reach. Orchestrators that consulted information sources beyond the PSN helped assuring higher levels of IQ-relevancy, IQ-completeness and SQ-accessibility. While we observed that all eight of the orchestrators only briefly scanned the environment (e.g., Twitter, chemical database and news site) for additional information, we doubt whether one person per team (i.e., orchestrator) may be enough to implement this principle. The orchestrators were very busy throughout the decision-making process and had little time to scan the environment. As such, further research needs to experiment with two or more roles that scan the environment for relevant information.

The *ninth* design principle (re-use information as much as possible) is one of the foundations of the DIOS prototype, allowing orchestrators to re-use information whenever possible. During the gaming-simulation with professionals, we have observed less instances of repeated information request when using DIOS. Since DIOS provided a shared information space or library, orchestrators could quickly determine if members of another team already shared the information they or members of their team were looking for. While the re-use of information reduces the SQ-response time and increased IQ-consistency, we need to underline that re-using information also increases the risks of re-using incorrect or outdated information. As such, orchestrators need to complement information re-use by quality rating and validation activities. Since some team or agency specific information may be more difficult to access for other teams, this design principles also improves the accessibility of information throughout the PSN. Therefore, this design principle helped in assuring IQ-timeliness, IQ-consistency, SQ-accessibility and SQ-response time.

The *tenth* and final design principle (make the owner of information objects responsible for updating its own information) helped assuring IQ-timeliness and IQ-correctness. Implemented as a task description for the orchestrators (when updates for an information object entered by yourself become available, update this object immediately), this principle made sure that information is updated at the source. We made clear that the information in the external sources (e.g., chemical database) was updated at the source, so that relief workers did not have to worry about the timeliness of that information. In addition, we noticed fewer discussions on the timeliness of the information in DIOS than in round 1. Yet, the way in which this principle is implemented and evaluated does not capture the original intention of this principle. This principle would require both public and private agencies collaborating during a disaster to take the responsibility for updating information. Because of the limited scope of the gaming-simulation in terms of participating agencies and data sources, we were unable to evaluate the impact of this principle to a full extend.

Returning to the last research question (do the proposed design principles assure higher levels of IQ and SQ for relief workers compared to a hierarchical information system) we conclude that following these principle assures higher levels for most, but not all IQ and SQ dimensions. From the start, we did not aim to evaluate the 'absolute' but the relative (compared) contribution of these design principles for assuring IQ and SQ. Overall, the data collected in the round 2 shows that the principles behind netcentric information orchestration assure higher levels of IQ-timeliness, IQ-correctness IQ-completeness, IQ-relevancy and IQ-format. When

we consider SQ, the design principles assure higher levels of SQ-accessibility, SQ-satisfaction, SQ-response time, SQ-information sharing support, SQ-notification and SQ-feedback. While the principles significantly assured dimensions such as IQ-timeliness and SQ-accessibility, dimensions such as IQ-correctness and IQ-relevancy proved to be more difficult to assure. Here, we also need to keep in mind that we did not include all the possible dimensions of IQ and SQ available in the literature. As discussed in Chapter 4, we left some dimensions of both constructs out of the scope of this research.

As we recounted, our quasi-experimental evaluation approach contributed useful information concerning the effectiveness of netcentric information orchestration. Side effects such as renegade freelancing indicate that the benefits of netcentric information orchestration are not without concessions. In the course of this study, we became increasingly conscious of the limitations of sharing information in a netcentric mode. Most importantly, the scope and design of the gaming-simulation did not always permit us to evaluate the full potential of each principle. Acknowledging that some principles are more difficult to implement and evaluate than others, the chosen gaming-simulation approach definitely influenced the results of the evaluation. We come back on this issue in the final chapter of this dissertation.

# 10 Epilogue

*"Follow effective action with quiet reflection. From the quiet reflection will come even more effective action"*

Peter F. Drucker (American educator and writer)

This statement by Peter Drucker captures the intention of this epilogue. In this final chapter, we reflect on three aspects of the research reported in this dissertation. Having discussed our research findings and conclusions extensively in the previous chapter, we first take some distance from the collected data and findings and ask ourselves what this research actually implies and contributes to science and society. Secondly, we reflect on the strengths and limitations of the taken design science research approach. Finally, we revisit the role of IT and the human factor in PSNs and conclude with avenues for further research.

## 10.1 Implications of netcentric information orchestration

Following a series of steps (i.e., empirical analysis, design and evaluation) and employing a combination of research instruments (i.e., observations, questionnaires and gaming) this dissertation presents ten design principles that have proven to assure higher levels of IQ and SQ for relief workers during disaster response. These principles are the cornerstones of our design theory, which we have labeled netcentric information orchestration. Netcentric information orchestration is a response to the observation that existing information systems (ISs) used for information management, do not satisfy the information needs of the variety of emergency services operating in PSNs. The existing IS architectures are characterized by top-down information flows which are connected to the authority structure, mono-disciplinary information management, and the generation of several static and agency specific operational pictures.

As a design theory, netcentric information orchestration suggest the redesign of existing information systems in such a way that collective intelligence can be orchestrated in real time throughout the entire network of agencies, without losing the benefits of existing (hierarchy based) decision-making and authority structures. While this design theory suggest some flattening of the hierarchical (vertical) IS architecture, we argue that the current three tier echelon authority structure (strategic, tactical and operational) needs to be retained, even when orchestrating information in a netcentric mode. As we have learned from our field studies, the three-tier echelon structure is a mixed blessing. One the one hand, the physical distance of teams operating on the strategic and tactical echelons allows commanders to remain calm and make decisions rapidly and free of emotions. On the other hand, the commanders have limited means to gather real-time information. Therefore, instead of flattening the three-tier echelon, netcentric information orchestration strives to provide an information platform empowering involved emergency services to be connected wherever and whenever necessary. This platform can supplement (and not replace) traditional channels of information sharing via radio

communication and can be used for establishing a dynamic common operational picture throughout the PSN.

As cornerstones of our design theory, the suggested design principles are intended to help stakeholders (e.g., IS architects, trainers, software vendors and policy makers) working on the design of IS for public safety and disaster response. These stakeholders have to consider a difficult tension in their design activities. During normal/non-crisis situations, there exist a need for tight structuring, formal coordination and top-down decision making to assure a clear division of responsibilities, formalized procedures and accountability. While these characteristics can be considered as the advantages of hierarchical information management, there is a competing need to rely on network-centric structures, enabling adaptive information flows, network wide information access (reachback) and ad-hoc information sharing during a disaster situation. Even though network based IS architectures promise some benefits over hierarchical approaches (e.g., higher adaptability, faster information distribution and shared situational awareness) the realization of such approaches in practice is still missing. Reasons for this include the major technical, organizational and training investments needed to leverage the promised benefits of netcentricity, whereas little scientific evidence exists on the effectiveness of this approach. Much of previous research has treated both modes of coordination separately or even as two extremes. The design principles presented in this dissertation helps to bridge both extremes by making an explicit distinction between information management and decision-making. In contrast to existing hierarchical IS architectures, netcentric information orchestration can start prior to the activation of decision-making teams and can become a continuous process (also taking place between the decision-making rounds).

Looking back in 2007, the former minister of Dutch Department of Interior Affairs and Kingdom Relations (BZK) stated that her department would have "resolved issues in disaster management within two years". If we look at conclusions of the recently published report on the Turkish Airline Crash in 2009, we can conclude that this goal has not yet been achieved. In the meantime, ISs for disaster response are gaining increasing interest of policy makers, relief workers and software vendors. Over the last five years, software vendors such as Microsoft and Google have launched several 'off the shelf' IT-applications for information sharing during disasters, including Microsoft GROOVE and Google WAVE. The growing number of proposed IT applications indicates that software vendors foresee a market in this domain. During our research, we observed that BZK is also taking some steps towards the implementation of an IT application (CEDRIC), which in their view is a netcentric information system. Similar to the Incident Commander Information System used in the United States, BZK is opting for a standardized nationwide information system for disaster management. Hence, several debates are currently taking place on whether a single IT application should be implemented across the Netherlands or not, what this should cost and how emergency services need to discard their existing IT applications. We see that many emergency services are still holding on to their current practices, sometimes being non-digital information tools such as whiteboards (e.g., Delfland field study). Since these debates are moving into a deadlock, this dissertation comes at a timely moment.

Considering the characteristics of PSNs (e.g., autonomy and pluriformity) and those of disasters (i.e., complexity and unpredictability), we strongly advocate principle-based design (see Chapter 6) as alternative to top-down information sys-

tem implementation (the strategy followed by BZK). In contrast to single, centralized solutions designed to share information in accordance to the hierarchy of decision-making (i.e., CEDRIC), netcentric information orchestration does not require all relief agencies to discard their current IT applications. Instead, netcentric information orchestration fosters the existing variety in the IT-landscape. Avoiding a single point of failure, netcentric information orchestration proposes on demand and event driven information collection, enrichment and distribution in PSNs. As such, information ownership is left to the respective public and private organizations, which are also responsible for updating their data. We argue that this retention of ownership is a prerequisite for organizations, which have commercially sensitive information, to share this information with relief agencies.

We should not forget the lessons learned from the top-down implementation of C2000, the national communication infrastructure in the Netherlands, mandatory for all emergency services since 2004. In September 2010, the national council of fire departments has again sent an official letter of complaint about C2000, emphasizing its poor SQ during incident response. Similar to the development and implementation of C2000, the central government again attempts to impose as single, uniform IT application for disaster response called CEDRIC. When browsing through CEDRIC brochures and user manuals, one will definitely notice the emphasis on a single, uniform system with a uniform (fixed) set of functionalities. As we learned from the Rotterdam field studies, this 'one size fits all' approach cannot avoid the IQ and SQ issues reported in this and other studies. Again, we see an attempt to move towards full centralization and standardization as means to abandon the current variety in the IT landscape. While the second version of CEDRIC has just been released and architects are working on the third version to be released in 2011, we expect that the centralized client-server architecture will be a major bottleneck for assuring IQ and SQ in PSNs. One of the reasons for this is that information that will be pulled into CEDRIC becomes the responsibility of the CEDRIC operators (information managers). We assume that this shift of responsibility is a barrier for organizations owning commercially or security sensitive information (i.e., Shell, KLM, Unilever) to share this information with relief agencies.

Getting CEDRIC adopted in all safety regions in the Netherlands does not only require a solid financing model, but also requires CEDRIC to perform well in terms of IQ and SQ. While a centralized IT solution such as CEDRIC is regarded by many as the current best practice in the Netherlands, the architecture of this application only satisfies the sixth principle (single window) and, partly the seventh principle (information library) proposed in this research. For this application to be successful in assuring IQ and SQ, the other principles presented in this research also need to be implemented. On an organizational level, this for instance means that the role of the information manager needs to be extended from 'note taker' to orchestrator (see Chapter 6). On a technical level, IS architects need to consider moving away from the traditional client server architecture to more flexible service oriented architecture implemented via state-of-the-art technologies (e.g., AJAX, Web Services). Our field studies also show that much work needs to be done on training information managers and coordinators. In many cases, the actors fulfilling these crucial tasks are not trained in recognizing and handling IQ and SQ issues.

## 10.2  *Reconsidering the scientific and societal contributions*

### 10.2.1  Scientific contribution

While applauding the steady increase of contributions on designing ISs for PSNs, design principles for assuring IQ and SQ were lacking in previous research. This research is the first to explore the theoretical pathways of netcentricity and orchestration. Accordingly, we are also the first to propose design principles for assuring IQ and SQ in a coherent way, despite the many IQ and SQ issues reported in disaster evaluation studies. In line with the classification of theoretical contributions provided by Gregor (2006), our theoretical contribution is type 5 (design and action theory). This type of theory says how to do something and gives explicit prescriptions (e.g., methods, techniques, principles of form and function) for constructing an artifact (i.e., prototype) needed for achieving specified goals. In light of our theoretical contribution, it is important to reflect on the 'seminal' scientific contributions provided in previous work. Four contributions can be considered seminal in this regard. First, is the vigorously cited paper by Delone and Mclean (1992) on IS Success theory (cited 3275 times in Google Scholar). Their work was important since it was the first to illuminate the importance of IQ and SQ. While these authors have made an important contribution on understanding the factors that make an IS successful within an organization, they are silent on pathways and principles for assuring IQ and SQ in a network of organizations. Our design theory, particularly the set of principles, can be regarded as an extension of the Information Systems Success theory by Delone and Mclean. Note that we have only tested our design theory in the context of disasters and PSNs. Since Information System Success theory is developed based on data from the business domain, we would first need to test our theory in that domain as well before we can claim to have contributed to this theory.

The second seminal contribution that we need to recall is the book on Organizations by March and Simon (1958). While the first print of their book is difficult to find, the reprint of this book (1993) is cited 11075 times in Google Scholar. Filled with ideas about the design of organizations, their work was a cradle for many theories in the management and organization sciences. Nevertheless, their work only focused on coordinating interactions within a single organization and did not prescribe any principles for assuring IQ and SQ in organizational networks. Moreover, many of their ideas remained ideas, without any further materialization (e.g., in a prototype) and evaluation of the impact they would have. By extending the concepts of advance structuring and dynamic adjustment from March and Simon, we were able to shape and categorize our design theory. Via our prototype, we demonstrate how these concepts can be implemented as means for assuring IQ and SQ in PSNs.

The third seminal contribution that was relevant for this research was the book by Alberts, Garstka & Stein (1999) on NCO. Cited 738 times in Google Scholar, their work introduced a vision of empowered soldiers and network wide information sharing. Drawing on the tenets of NCO, our work is the first that has deepened, demonstrated and evaluated the pathways of NCO in relation to IQ and SQ. By providing design principles to stakeholders (e.g., IS architects and policy makers), this research aims to contribute in assuring IQ and SQ in PSN, and ultimately improved disaster response. Acknowledging that other factors (e.g., cognitive capabilities, training etc.) are also crucial factors when it comes to improving disaster

response, these are considered outside the scope of this research, as is the effect of IQ and SQ on the efficiency and effectiveness of disaster response activities. If we were to step outside the boundaries of this dissertation, we assert that the proposed designed principles are a first step to fully enabling sense-making (Weick 1995) as ideal type of group decision-making. The concept of sense-making as a more accurate and realistic decision-making model under time pressure (for instance compared to the Observe, Orient, Decide and Act model discussed in Chapter 1), rests upon the assumption of information symmetry between individuals. Since having the same input information is one of the assumptions of sense- making, a network wide information pool, such as the one described in this dissertation, can be considered as a prerequisite for sense-making.

The fourth seminal contribution, orchestration, is a concept that cannot be attributed to a single author, book or paper. Since the earliest mentioning of this concept in Neurath (1946, originally 1916) various scholar have gradually expanded our understanding of this concept, often as a vision for coordinating a variety of specialized resources in concert. While this idea has been around longer than the other contributions mentioned earlier, no single paper or book has been able to capture essence and implications of orchestration in a broader, socio-technical context. Instead, we see that scholars investigating technical means for coordinating processes and web-services in supply chains have taken up this concept. Considering existing literature, we are the first to have materialized this vision in relation to IQ and SQ and in the context of public safety. By relating orchestration to some concepts from coordination theory (e.g., boundary objects and mediation), we have extended this vision as a pathway for assuring IQ and SQ and have specified the capabilities needed to orchestrate information in a network of organizations.

Before this research, there was little empirical data on the type of applications used, the information flows between agencies and the roles developed for multi-agency information sharing. Also, there was no prior investigation conducted on the type of IQ and SQ issues experienced in PSNs. Looking back, it was not strange that our publications containing rich empirical data received a 'warm welcome' in various scientific communities (see reference list). From a scientific perspective, this dissertation provides rich empirical data on the design of information system architectures in practice. This dissertation also shares data on the IQ and SQ issues experienced by relief workers in practice. We consider these sets of empirical data 'rich' since we collected these data sets using several instruments (i.e., surveys, observations and interviews). Using these instruments, we have described several components of information system architectures used in disaster response situations. The empirical data is also rich because it is both qualitative and quantitative in nature. Scholars can use the presented empirical data for further research purposes.

## 10.2.2  Societal contribution: guiding stakeholders in PSNs

Every researcher, especially the ones focusing on design and prescription, should ask themselves: *who is waiting for this dissertation?* In retrospect, we have asked ourselves this question several times during this research, and every time, the answer included a different set of actors.

At the start of this research, we considered that our work would help society in general and relief workers in specific. During our field studies, it became clear to us that exercise organizers and trainers were the ones shaping the relief workers

of tomorrow. Therefore, we expected that they would benefit from the systematic evaluation on IS architectures and the impact on IQ and SQ provided in this research, especially since this has never been done before. Trainers could also use our observation protocol and survey to expand their exercise evaluation instruments beyond individual and team performance measurement.

When starting the interviews with IS architects, we realized that they were also very important stakeholders when it comes to information management during disaster response. As designers of IS architectures, they were the ones that could truly help in assuring IQ and SQ for relief workers. Architects could for instance employ the principles provided in this dissertation in their current practices and systematically reflect on their practices using the IQ and SQ dimensions. During the interviews, we also understood the role of policy makers on the local (municipality), regional (Safety region) and state (ministerial/ Dutch Department of Interior Affairs and Kingdom Relations) level. As important funders of IS for disaster response, these public officials would benefit from our analysis of existing PSNs and set of principles stated in this dissertation.

Another audience we did not anticipate in the beginning of this research consists of software vendors and IT consultants. Throughout our field studies and interviews, we have learned that an increasing number of software vendors (e.g., CityGIS, Microsoft and Google) and IT consultancy firms are trying to establish a market in PSNs. In many cases, software products developed for different domains and purposes (e.g., business intelligence and group collaboration) are advertised, to date without much success. Accordingly, software vendors and IT consultancy firms could employ the empirical foundation of this dissertation for a better understanding of information management, IQ and SQ in the domain of disaster response.

## 10.3  Reflection on our research strategy

### 10.3.1  Design science research

The choice of a methodological approach in a research project influences not only which explanations we may find, but also which mechanisms we may tend to neglect. Considering the scarce knowledge on assuring IQ and SQ, as well as our objective to prescribe principles, the prescription-oriented design science research approach was quite appealing to us when we started this research. Perhaps only a few novice researchers can neglect the lure of "the ability to balance rigor and relevance," a benefit one can deduce from most papers on design science. Design science research has come a long way since first coined by Herbert Simon in "Sciences of the Artificial," 1969. Simon discussed design science in the contexts of economics, psychology of cognition, and planning and engineering design, but not ISs. It took some time before Simon's ideas filtered through to ISs community and they are still not widely accepted in this discipline. It is only since the seminal paper by Hevner et al., (2004) that this approach 'revived' within the ISs community. While some proponents of this approach consider it as a completely different paradigm when it comes to conducting research, we experienced that this approach is far from being a paradigm. Instead, this research strategy is still in its early stages and needs to mature on at least two aspects before it can be labeled a 'paradigm'.

These aspects include (1) ironing out the relationships between theoretical knowledge and empirical findings and (2) the many degrees of freedom on how to

formulate a design theory and on what basis to draw conclusions. Because design science allows researchers to collect both qualitative and quantitative data using a combination of research instruments, we found it difficult to decide upon which data we would actually draw our conclusions. While we took some distance from using solely positivistic or quantitative methods in Chapter 2, the conclusions in this dissertation still rest firmly on the quantitative data collected from the surveys. While acknowledging this 'positivistic tendency' in the evaluation cycle, the empirical and design cycles rest firmly on the qualitative data. While the many degrees of freedom was a nightmare for the author as a starting PhD level researcher, it proved to be more facilitating once the author gained experience in its application.

Since design science research emphasizes the need for constructing solutions to complex socio-technical problems, we argue that this approach allows scholars to make a more equally balanced contribution to science and society, something that is difficult when following only the positivist or interpretive paradigms. However, balancing rigor and relevance is one of the tensions inherent in design science research. Often this is a false dichotomy and the two are not mutually exclusive. It is important in a dissertation to carry out rigorous systematic research underpinned by an appropriate epistemology or theory. This does not mean that your dissertation cannot address a practical problem. It does mean that you have to have a theoretical framework to explain your theory of change.

In retrospect, the key to applying the design science research is to transcend the epistemological debate and understand the results of every cycle in light of other forms of theory. The article by Gregor (2006) formed an important basis for conducting design science research. Gregor provides a useful categorization of theories that considers design theory as a 'category five' theory or theory for design and action. Based on the completion of four cycles in design science research (rigor, relevance, design and evaluation) we now advocate the importance of pathways in kernel theories, empirical grounding, triangulation of data and the continuous refinement of data collection instruments. When considering existing contributions on how to implement design science research (see Chapter 2), we argue that our way of adapting and executing this approach can guide others interested in the application of design science research.

## 10.3.2  Gaming-simulation

In our quest to evaluate the proposed design principles under conditions that resemble a disaster, we chose to apply the gaming-simulation methodology. While scholars and practitioners have employed this methodology for educational purposes, it is only recently that scholars have started using this methodology for evaluation purposes. Compared to other IS evaluation methodologies (code testing, surveys and case studies), gaming-simulation allows for controlling contextual interferences and ruling out alternative explanations as prerequisites for construct and external validity.

In contrast to other evaluation methods such as case studies and surveys, gaming-simulations are versatile and can be executed as quasi-experiments. Compared to case studies and surveys, gaming-simulations offer a relatively large degree of control for researchers. For instance, when planning subsequent rounds in a gaming-simulation, each round can entail different scenarios, loads, resources (i.e., information technology) and data collection instruments, enabling a controlled issue of a specific treatment (e.g., design principles). The controlled conditions can

be shaped in such a way as to resemble the characteristics deemed salient in the reference situation. For evaluation purposes, all the internal validity criteria are relevant, and have to be considered when interpreting the results of the gaming-simulation. In addition, for researchers, gaming-simulations can be very helpful in bridging the proverbial gap between theory (e.g., in the form of principles) and practice. Both the creation and the execution of gaming-simulations can provide researchers with new and additional insights with regard to disaster response related processes, including decision-making and information management.

Finally, this research is one of the few contributions that demonstrate the use of gaming-simulation for evaluating design theories. While scholars such as Meijer (2009) have demonstrated the value of gaming-simulations for evaluating design theories in the context of supply chain management, this research shows how this approach can be applied in the context of disaster management. As such, we provide an explicit set of experimental variables in order to evaluate a design theory, including roles, rules, activities, scenarios and data collection instruments. We consider this as a contribution since previous work is silent on the evaluation of design principles. Configured as a quasi-experiment with professional relief workers, our gaming-simulation allowed us to investigate the effects of netcentric information orchestration on IQ and SQ during disaster situations.

### 10.3.3 The importance of empirical grounding and working practices

Even though we only conducted one quasi-experiment with professionals, our findings show some promising results on assuring higher levels of IQ and SQ for relief workers. Considering the external validity of our findings, does this mean that netcentric information orchestration will assure higher levels IQ and SQ during future disasters? Our answer is perhaps, but only when some conditions are in place.

We argue that significant doubt must be cast on the notion that we can 'validate' an IS architecture at a given point in a research if we accept that the use of an IS architecture is not completely determined by the principles it is based on. This means that the external validity of the proposed netcentric information orchestration principles depends, at least in part, on the success or failure of new working practices. As discussed by Venkatesh (2003) there are a vast range of reasons why IS usage in practice may vary from research settings, even within a single organization. ISs put implemented in practice may initially fail because they do not resonate with existing work practices, policies or professional cultures. Moreover, inadequate training programs, the prevalence of 'fear and loathing', and the breakdown of new organizational processes may all affect the speed with which systems become 'usable'. Equally, tested and trusted information systems may begin to fail as changes in the organizational and work environments begin to have impact upon them. As Davenport (1993) points out, changes in work activity may take years to become manifest, and the impact may not, even if apparent, be straightforwardly measurable. If this is true, it indicates that evaluation must be extended not only into the whole of the conventional design process, but also well into the system's useful lifecycle. That is to say, evaluation work will have to be conceived of not as something separate from other stages in the design process, but as a necessary feature of all design work.

Furthermore, substantial re-conceptualization of the notion of ISs and its boundaries will be necessary if we are to be serious in our attempts to evaluate IS

use. Similar to solutions developed for risks aversive sectors with high failure cost (e.g., airline industry, nuclear power plants), further IS evaluation using live piloting is difficult in public safety networks. Accordingly, we suggest that the main challenge for future research is to investigate supporting and impeding factors for 'grounding' netcentric and IT-enabled information orchestration in existing hierarchical information management architectures.

### 10.3.4  Limitations of this research

This research is not without its limitations. We highlight two sets of limitations in this section. The *first* set of limitations is rooted in our field study approach. We heavily draw on data collected from training exercises and fictitious disaster response scenarios. While these training exercises were set up in such a way that they closely resembled real disasters, we cannot rule out disturbing factors that may emerge during real disasters. The fact that the exercises were fictitious also adds some bias to our quantitative data. The relatively small number of field studies can also be regarded as limitation. Moreover, the number of observers was small (two, sometimes three observers), limiting the number of information flows we could observe. While the three field studies have provided us with rich (qualitative and quantitative) data, we cannot say that our sample is representative for all of the existing PSNs in the Netherlands or in other countries. Moreover, because we only studied PSNs in the Netherlands, the external validity of our results is limited to the Netherlands.

The *second* set of limitations is rooted in our quasi-experimental gaming-simulation approach. Firstly, we have only tested our design principles with a single group of graduate students and a small set of professionals. Admitting that the evaluation of our design theory during a real disaster would count as the most realistic form of evaluation, gaming-simulation allowed us to compare the effects of netcentric information orchestration to hierarchical information sharing in a safe and controlled environment. Generic conclusions require repeated runs with the gaming-simulation. Perhaps repeated sessions with larger groups of relief workers will improve the (statistical) reliability of our results. However, repeated sessions of three to four hour gaming-simulations are expensive and difficult to organize because the work schedules of relief workers provide few options for experimentation. Moreover, repeated runs are not completely comparable since the players show learning, fatigue and so on.

Secondly, while we had a perfect fit of respondents (professional relief workers) in our quasi-experiment, twenty-four participants result in a small data set for quantitative analysis. Such small sample sizes do not cancel out individual biases in the data and prohibit researchers from applying more advance data analysis techniques (e.g., structural equation modeling and path analysis). On the other hand, the relatively small sample size was well manageable and allowed for more focused qualitative data collection with a limited team of observers.

Finally, the two scenarios we used during the gaming-simulation sessions were quite comparable and included a limited range of events, hazards and risks. As main component of the two experimental loads, the scenarios needed to be comparable in their complexity. In addition, complex scenarios such as terrorist attacks and floods require longer rounds of gaming and more explanation (i.e., events and messages) towards the participants.

## 10.4 A research agenda

### 10.4.1 Revisiting the role of IT

Disaster researchers such as Quarantelli and Comfort have frequently underlined that IT should not be viewed as a panacea for all problems during disaster response. Reducing the impact of disasters requires an adaptable, and partly unpredictable, mix of technical and social components, and no single scientific discipline can provide all the answers. While IT may help getting the right information to the right person on the right time, we argue that the right use of information by relief workers is at least as important for assuring IQ and SQ. While we foresee further adoption of ITs in PSNs, the future of ITs in this domain depends on the right mix of supporting roles, capabilities and training procedures. As such, we applaud the gradual shift in the research community on information systems for disaster response (ISCRAM). Having visited three consecutive ISCRAM conferences, we observed that more and more scholars are investigating the development of IT from a socio-technical perspective, promising valuable and directly useable results for professionals and policy makers.

Drawing on our field study observations, we conclude that there is a low level of trust in IT amongst the relief workers. Quoting one of the leaders of a COPI team in the Rotterdam-Rijnmond field study who purposefully neglected the IS (CEDRIC) and used a whiteboard: "a hundred years ago we also did it like this and it always worked, I refuse to use anything that sometimes does not work". This relief agency commander explained his disappointing experience with electronic means for communication (C2000) and was dedicated in avoiding the use of IT in disaster response. Some extra questions however led us to conclude that this very experienced relief worker was not very advanced in the use of electronic means for information sharing, indicating a low level of IT-readiness (defined as the ability to employ IT for tasks execution).

From this interview and other observations, we concluded that a low level of trust in existing IT due to previous IT failures, combined with a low level of IT-readiness, reinforces the reluctant attitude towards the adoption of IT in this domain. This is not necessarily a 'bad thing'. Disaster response is a hazardous and very important task, so there needs to be zero tolerance for IT failure. This however does not mean we need to turn our heads away from IT innovations that hold the potential to radically improve information sharing during disaster response and ultimately safe lives. If we were to draw a spectrum of disaster types, ranging from often occurring incidents (e.g., a fire or car accident) to almost never occurring total devastation (e.g., atomic bomb), IT would be able to cover a wide range of this spectrum. Moreover, we see significant efforts from the private sector and the academic community to further increase the capacity and resilience of existing IT infrastructures, for example via the role out of fiber optics and next generation mobile platforms such as HSPDA. Research on for instance 'graceful degradation' and multi-tolerant systems (i.e., Gariel, 2010) also shows promising results towards retaining some minimal IT service levels after infrastructure failure. Thanks to such advancements, we expect that future IT-based IS for disaster response will be even more resilient and less susceptive to infrastructure failures. Nevertheless, there are still several challenges requiring further research. We discuss some of these challenges in the next subsection.

### 10.4.2 Six recommendations for further research

While reflecting on the findings of this research, six main avenues surfaced for further research. These recommendations are more generic (not principle related) and complementary to the recommendations provided in the final section of Chapter 9. We present these avenues as recommendations for scholars, practitioners, software vendor and policy makers since we expect that their collaborative efforts will lead to the most useful results.

The first avenue for further research is on preparing relief workers to utilize the capabilities provided by network based information systems. While we have extensively discussed the technical and organizational requirements behind this way of information management in Chapter 7, we have not investigated how to prepare relief workers to decide and act in an environment with advanced information management capabilities such as reachback and information rating. The

*Recommendation 1: Conduct research on training programs that prepare relief workers for the effective employment of the capabilities provided by netcentric information systems*

quasi-experimental gaming-simulation revealed that not all of the participants knew how to employ the functionalities provided by DIOS. As a result, some of the participants were not fully able to deal with the amount of information that was suddenly available (compared to the first round). Furthermore, we noticed that not everyone was comfortable with the idea that the information they shared can be viewed by everyone in the network. We noticed that for some participants, it was part of their routine to disclose information from others within their own agency and outside their agency. In addition, from what we have observed in our field studies and gaming-simulation, relief workers often think about themselves as representatives of their agency and focus on retrieving the information they and their agency needs. However, in order to fully utilize the capabilities and benefits of netcentric IS architectures, relief workers need to understand that they are part of a network and think about the information that others beyond there agency may need. While this form of boundary spanning is to some extend assured through the role of the orchestrator, further research needs to investigate instruments for helping relief workers through this transformation. In addition, we predict the need for developing norms for information orchestrators. These norms, both qualitative (e.g., are consistency checks executed) and quantitative (e.g., time needed to validate information), can further help orchestrators to learn and improve their processes.

A second research avenue surfaced from this research is the potential of using citizen and media generated information to supplement information in multi-agency teams. Practitioners such as O'Reilly (2007) have already analyzed the power of harnessing the "wisdom of the crowds" and Web 2.0 in business environments. The 2009 Turkish Airline Crash in the Netherlands is just one of the examples in which relief agencies could have benefited from data in social networks such as Twitter (e.g., for triangulating the exact location of the plane crash). While we

*Recommendation 2: Conduct research on ways in which citizen and media generated data can be pro-actively used for assuring information quality in multi-agency teams*

have included some basic functionalities for accessing information from social net-

works (e.g., Twitter), this research has tapped upon the potential of using citizen- and media-generated data from social networks during disaster response. As we have learned during our field studies, the increasing mediatization of disaster holds both opportunities and challenges for emergency services since the media covers both facts and rumors. Often, but not always, the media arrives on the disaster site at the same time relief agencies arrive. While relief agencies focus on how to respond to the events that occur, the media focuses on pulling information from bystanders, witnesses and sometimes even victims. As such, the media is often considered as a nuisance to the response process. While the DIOS platform does allow for harnessing collective intelligence, we opt that this platform can be extended in such a way that the media and citizens can also be employed as sensors for information. Some of the collected information from the media (e.g., about the source of the disaster) and citizens (e.g., exact location of a gas tank) could add to the common operational picture that relief agencies are trying to create. Despite these potentials, we have observed that the information gathered by the media and citizens is often not intentionally captured by relief agencies. We have even observed situations in which a mayor speaking to the press is confronted with information from the media that his team was actually looking for, leading to a somewhat embarrassing press conferences. Accordingly, we suggest that further research focuses on how to capture high quality information from the citizens and the media. One example we can think of here is to dedicate orchestrators to the triangulation of data from various internal and external sources while focusing on low rated IQ quality scores for specific information objects (e.g., about the location of a disaster, number of casualties etc.). This for instance could lead to an real time and two-way 'architecture of participation' allowing relief workers to remix data from multiple sources (e.g., individual citizens active on Twitter or personal Weblogs, news sites etc.), while some disaster related information available in the PSN is provided in a form that allows remixing by journalist and citizens creating extensive network effects.

A third avenue that surfaced from this research is the emergence of 'renegade freelancing' by relief workers acting on their own interpretation (and consequently ignoring the guidance from higher command). As discussed in Chapter 8 on the quasi-experimental gaming-simulation, subordinates having access to information beyond their responsibility are enabled to make decisions out of sync with the commanders intend. This kind of deviation from higher intent is both

*Recommendation 3: Conduct research on dynamic information access/viewing and posting controls and policies for network based information management approaches.*

unpredictable and unexpected, may present serious problems to a unified response effort and is perhaps one of the most dangerous side effects of network based information sharing and reachback. Since we have only briefly discussed this phenomenon, we opt that further research looks into ways of dealing with this issue, for instance, through the implementation of dynamic (context dependent) information viewing and posting controls.

A fourth avenue is on fallback options in case of IT and infrastructure degradation. The use of IT is increasingly becoming a goal, instead of a tool for information management during disasters. This trend has a dangerous flipside. What if the infrastructures (e.g., electricity, internet, mobile network, hardware etc.) fail? This question should remain on the agenda of policy makers, relief agency com-

manders and architects and exercise organizers. Since infrastructure failure during disasters is not uncommon, we need to develop and retain not IT based information management skills and resources. While acknowledging that our background in IT makes us advocates for using IT, we acknowledge that the dependency on any IT solution (e.g., CEDRIC, DIOS) needs to be as low as possible. This research has neither studied the

*Recommendation 4: Conduct research on developing and training easy to learn and non-IT based fallback approaches for information management in case of infrastructure failure*

fallback options in case of electricity, internet or hardware failures, nor in the case of the total destruction of infrastructures. Even though we are convinced that 'high tech" information system applications such as DIOS are able to assure higher levels of IQ and SQ for relief workers, fallback on 'low tech' pen and paper (or whiteboard) solutions are still required. While fallback may not be necessary in many cases because of the precautions taken by relief agencies (e.g., mobile radio towers on trucks, backup electricity generators in COPI rooms and hospitals), devastating disasters such as tsunamis and earthquakes may still require that relief workers share information using pen and paper. Since we did not come across any research that investigates procedures or principles needed to guide relief workers in the transition from high tech solutions to low tech solutions, we strongly encourage scholars to conduct research on this topic.

A fifth avenue for further research concerns the development of stable interfaces for adaptive IT. There are an increasing number of scholars focusing on developing adaptive ITs for several domains, including PSNs. Anticipated contributions include adaptive user interfaces, changing functionality portfolios and situation dependent visualizations. The general idea is that ITs needs to be more intelligent and software agents need to fulfill more tasks instead of humans. While applauding these research efforts, our experience from observing relief workers in their operations is that they prefer interfaces and functionalities that they know by

*Recommendation 5: Conduct research on how to keep the interface between information technology and relief workers as stable and familiar as possible while the portfolio of services keep adapting to changing circumstances*

heart and are used to, instead of changing user interfaces and 'new' functionalities depending on the situation. When almost everything in their environment seems to be subject to change, relief workers prefer to hold on to their standard procedures and routines, so they can react immediately instead of having to first understand the technology in front of them. While we have also tried to balance adaptation with routine and well known interfaces (i.e., using AJAX technology), we have not investigated means to minimalize interface changes through service portfolio adaptation. Therefore, we pose this recommendation as a challenge for the scholars who are working on adaptability and adaptive IT.

The *sixth avenue* for further research surfaced from this research is about the right use of information on the individual level. A well-known 'mantra' in the domain of information systems for disaster management is 'getting the *right* information to the *right* people at the *right* moment.' We have read this mantra, both as a challenge and as an advertisement in several reports. As we progressed in this

research we have also come across research on the adding a fourth 'right' to this mantra, information the right format. Having completed this research, we belief that a fifth right is still to be studied: the right use of information. The right use of information is not captured in the IQ and SQ constructs of this research. Independent of the quality of information available to an individual or team, wrongful interpretation and use of information may significantly affect decision-making process-

*Recommendation 6: Conduct research on principles that can guide relief workers towards the right use of information as extension to getting the right information to the right person at the right time and in the right format*

es during disaster response. While we have studied the use of information on the level of team information manage-

ment, we have not thoroughly investigated the use of information on the individual level. Recently, a disaster in Amsterdam reminded us of what happens when 'no one thought about it'. After an explosion in an apartment building on the 25th of July 2010, the neighbors had been informed the day after the explosion that was a possibility that asbestos was released and that they should evacuate the area. Of course, this information was shared too late. While the official investigation report still needs to be released, we can assume that no one remembered to discuss whether information on asbestos release should be shared or not. In the hectic and stressful time of a disaster, relief workers tend to be blindsided and focus on the immediate mitigation of the disasters. The movie "World Trade Center" released in 2006, allows one to get an impression of the level of stress, time pressure and desperation dominating every second of the disaster response process. Here, we should not forget that time pressure can decrease the performance levels of less experienced decision-makers even in the presence of complete information (Ahituv, Igbaria, and Sella, 1998). As a result, obvious and trained protocols sometimes do not come to mind. Our field studies showed that simple checklist have been replaced by comprehensive disaster response handbooks and manuals. Alternative means, such as the information library in DIOS could help in collectively and systemically browse through information needs quickly while having access to the knowledge gained from previous disaster response efforts.

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# Summary

## Introduction

Recent response efforts to large disasters, such as the 2009 Polderbaan plane crash, reveal that inter-agency (horizontal) and inter-echelon (vertical) information management remain major challenges in public safety networks (PSNs). Currently, the various relief agencies (e.g., police departments, fire departments and medical services) manage information independently (in silos) and in accordance with their daily routines and hierarchical organization structure. From the perspective of each relief agency, their hierarchy-based information systems perform sufficiently during daily, non-disaster situations. However, the ad-hoc combinations of such information systems often fail in assuring information quality (IQ) and system quality (SQ) for multi-agency teams during disaster response. Yet, literature provides little guidance for stakeholders (e.g., information system architects, policy makers, software vendors and trainers) when it comes to assuring IQ and SQ during disaster response. The objective of this dissertation is to synthesize and evaluate design principles that assure higher levels of IQ and SQ for multi-agency teams. The prescription oriented Design Science research approach led this research, and required us to complete four cycles: a rigor cycle (drawing on theory), a relevance cycle (drawing on empirical data), a design cycle (synthesis of design principles) and a evaluation cycle (prototyping and quasi-experimentation). The design cycle draws on the findings from the rigor and relevance cycle, and introduces "netcentric information orchestration," a design theory for assuring IQ and SQ during disaster response. The evaluation cycle revealed that netcentric information orchestration assures higher levels for most IQ and SQ dimensions compared to hierarchy based information systems.

## The hurdles for assuring IQ and SQ in public safety networks

Assuring IQ and SQ in complex, ad-hoc and unpredictable environments such as disaster response is major challenge. Not only are the response conditions stressful and hazardous, the agencies involved in the PSNs are also heterogeneous and incompatible on several aspects. During disaster response, several public and private agencies team up in a PSN with the collective objective of protecting civilians from the hazards brought by a disaster. In such a network of agencies, inter-agency and inter-echelon information management are crucial for the performance of multi-agency teams. In this context, information management is a cycle of activities including the collection, preparation, storage, validation, enrichment and distribution of information. These activities need to take place between different agencies (inter-agency) and between the strategic, tactical and operational echelons (inter-echelon). Recently, policy makers have introduced legislation on PSNs in order to correct decades of isolated, ad-hoc, and poorly supported IT development practices among and within relief agencies. However, our analysis of the professional and academic literature, as well as empirical field research, indicates that there is great variety in types of information systems being developed under the umbrella of "public safety" systems. This variety spans technological feature sets, organizational arrangements, governance practices, jurisdictional scope, and institutional envi-

ronments. One key commonality is that PSNs involve several agencies, meaning they may span governmental levels (i.e., federal, provincial, local), functions (e.g., police, fire, justice) or geographies (i.e., municipalities, regions or communities).

As the severity of a disaster increases, PSNs unfold in three echelons: strategic, tactical and operational (field units). In accordance to this hierarchical organization structure, both multi-agency and mono-agency teams are activated. While the output of these teams includes decisions and actions, the input for these teams includes a situation dependent mix of information, actions and events. However, the multi-agency information management process is often hampered due to the capabilities embedded in the design of the underlying information system architectures. Here, information system architectures represent the blueprint and configuration of both social and technical components of an information system. As such, information system architectures dictate the information management capabilities that can be developed prior to or during disaster response.

One will find multiple hurdles when studying the social and technical components of information system architectures. First, each relief agency has its own specialization and information needs and therefore they "join up" their individual IT standards, policies and applications for the purpose of inter-agency (horizontal) and inter-echelon (vertical) information management. In practice, the compounded information systems of the various relief agencies are incompatible, hampering inter-agency and inter-echelon information management. Secondly, both the information supply and demand are scattered throughout the network of agencies and are difficult to determine in advance. Thirdly, the information supply and demand are fluid and are difficult to demarcate since a relief worker can be both the source and receiver of information objects. Finally, the uncertainty inherent to disasters makes it difficult to pre-establish flows and pre-determine information needs. Since the information systems of the individual relief agencies are designed to support daily, routine and intra-agency information needs, they often fail to assure IQ and SQ throughout a network of agencies.

**Rigor cycle: measurement instruments and pathways for IQ and SQ**
In the first cycle, we constructed the theoretical foundation of this research by reviewing literature on IQ, SQ, coordination theory and network centric operations (NCO) theory. In this phase, we investigated two sub questions. The first sub question (1a) asked what a useful and tested framework provided is for studying IQ and SQ. We found that IQ is a well-studied construct covering over thirty dimensions, including relevancy, timeliness, completeness, accuracy, consistency, amount and format. SQ on the other hand is a less coherently studied concept that includes five key dimensions including accessibility, response time, flexibility, reliability and interoperability. Even though the Information System Success Theory emphasizes the importance of IQ and SQ for information systems success, this theory is silent on principles for assuring IQ and SQ. Accordingly, we formulated sub-question 1b as, *what pathways are provided in coordination theory and netcentric operations theory for assuring IQ and SQ in public safety networks?* Based on our examination of both kernel theories, we derived seven pathways, four from coordination theory and three from NCO. Pathways from coordination theory include advance structuring, dynamic adjustment, boundary spanning and IT-enabled orchestration. Pathways from NCO theory include reachback, self-synchronization and information pooling. While these pathways formed the theoretical basis for our de-

sign theory, we still needed to gain more insights on information system architectures, IQ and SQ issues in practice.

**Relevance cycle: field studies and empirical data collection**
Equipped with the IQ and SQ assessment instruments from literature and knowing the pathways from theory, we entered the second cycle of this research. This cycle focused on investigating the empirical context of inter-agency and inter-echelon information management during disaster response. Since previous work did not provide much description on existing information management systems and practices, we decided to conduct exploratory field studies. We conducted three field studies: Rotterdam-Rijnmond, Gelderland and Delfland. Throughout these field studies, we set out to answer three sub-questions.

The first sub-question (2a) asked about how multi-agency teams manage information during disaster response in practice. As essential part of the field studies, we observed 22 different disaster response exercises in the Netherlands. The exercises were observed based on an observation protocols crafted for studying the information management process, roles, capabilities and information/system quality issues. We investigated this question by collecting, analyzing and triangulating observational data, available documentation, informal talks with relief workers during training exercises and discussions with exercise trainers before and after training exercises. Our observations reveal that inter-agency and inter-echelon information management takes place via multiple channels (voice, text and visual). Moreover, the roles and capabilities for inter-agency and inter-echelon information sharing are designed for hierarchical operations and are non-adaptive to situational needs. In general, information flows according to the hierarchy based command and control structure. This architecture for information sharing resonates with a functional hierarchy. This means that commanders brief subordinates on a very limited 'need to know' basis and are often oblivious to the wider context and significance of their actions. This reflects the belief that the most effective disaster response is carried out under rigid control exercised from a hierarchical command structure. In such hierarchy-based information systems, subordinates should always report only to their commanders and teams, including the emergency control room, are limited in their capabilities for assuring high levels of IQ and SQ.

Considering the various information system architectures in practice, the second sub-question (2b) asked about which levels of IQ and SQ existing architectures assure for relief workers during disaster response. We investigated this question using surveys. The surveys included IQ and SQ items that other scholars have tested in previous studies (see Lee et al., 2002; Nelson et al., 2005). In total, we collected 177 completed surveys, of which 153 were suitable for data analysis. We prepared and analyzed the collected survey data using SPSS. The CEDRIC application in the Rotterdam-Rijnmond case allowed us to study information management using a single IT application. This single IT application based information system scored relatively high on IQ-consistency, IQ-relevancy and IQ-correctness, but low on IQ-timeliness, SQ-accessibility and SQ-response time. In the Gelderland case study, we observed the effects of using multiple IT applications for information management. This multi-IT application based information system scored relatively high on IQ-correctness, IQ-relevancy and IQ-timeliness, but low on IQ-completeness, IQ-consistency and SQ-accessibility. Finally, in the Delfland field study, we collected data on the use of whiteboards as non-IT based information

system. The participants rated the use of whiteboards for information management high on IQ-correctness, IQ-consistency and IQ- relevancy, but low on IQ-completeness, SQ response time and SQ-accessibility. On a cross-field study level, the survey results indicate the relief workers are generally satisfied with the IQ and SQ, despite the fact that accessibility, response time, reliability and information completeness were sometimes problematic.

The third sub-question (2c) asked about what the existing best practices of information system architects are for assuring IQ and SQ. This question was asked because we were convinced that information system architects not only have a better understanding of existing IS architectures than we had, but also that they would be the best judges of the pathways we had surfaced from literature. We investigated this question by interviewing sixteen senior information system architects working at various relief agencies in the Netherlands. After conducting the interviews and checking the transcripts with the interviewees, we coded and analyzed the transcripts using ATLAS.ti for advanced qualitative data analysis. Generally, the information architects felt that SQ, especially creating interoperability across agency databases is currently the priority whereas IQ is a future concern. In addition to understanding existing information system architectures, the interviewees helped us to further explore and shape the seven pathways provided in NCO and Coordination theory. While the interviews surfaced NCO and service oriented architectures (SOA) as future 'good' practices that may assure IQ, the current practices converge on assuring SQ-interoperability and SQ-response.

**Design cycle: redesigning information systems for IQ and SQ assurance**
Equipped with the pathways derived from theory, as well as empirical data collected from practice, we entered the design cycle of this research. The research question (question 3) we addressed in this cycle asked about which design principles could assure IQ and SQ during multi-agency disaster response. This question invited the main theoretical contribution of this dissertation and challenged the author to synthesize design principles, that when applied by stakeholders would assure higher levels of IQ and SQ than existing, hierarchy based information systems. Drawing on the kernel theories (coordination theory and NCO), as well as our field study findings, we advocate a more decentralized approach for inter-agency and inter-echelon information management during disaster response. We call this approach netcentric information orchestration, a design theory based on ten design principles, including the re-use of information and information rating.

Netcentric information orchestration proposes the development of dynamic information management capabilities prior to (advance structuring) and during disasters (dynamic adjustment). Advance structuring promotes maximizing reach-back capabilities and diversifying information sources for triangulation purposes. This pathway suggests preemptive and protective measures for structuring inter organizational information flows. Advanced structuring involves reducing task interdependence through loose coupling, and mitigating resource dependency by diversifying resource allocations (e.g., creating alternative information sources). On the other hand, dynamic structuring promotes active environmental scanning and information quality feedback by means of rating. The primary theoretical basis is the learning based sense and adapt paradigm. In this way, the orchestrator supplements the emergency control center, which only pushes information and does not monitor the quality of information. Avoiding a single point of failure, netcentric

information orchestration proposes the alternative of real-time, demand based and event driven information management between agencies and echelons in PSNs. Here, information ownership is left to the respective public and private organizations, which are left responsible for updating their data. This retention of responsibility is an important prerequisite for organizations that possess commercially or security sensitive information and, in case of a disaster, need to share this information with relief agencies. Furthermore, the netcentric information orchestration approach is scalable since there is no limit to the number of orchestrators that can join different multi-agency teams on the spot.

As cornerstones of our design theory, the suggested design principles are intended to help stakeholders (e.g., IS architects, trainers, software vendors and policy makers) working on the design of IS for public safety and disaster response. The ten design principles for netcentric information orchestration allow stakeholders to harness existing diversity in the various information system architectures used in PSNs. Diversity refers to the different software applications, roles, information objects and policies. In contrast to uniformity, ('one size fits all' information system), diversity caters a wider information supply and allows for dynamic adjustment during disaster response. Netcentric information orchestration does not require that stakeholders use the same IT application and discard their current IT-applications. Instead, technical standards such as XML allow for loosely coupled information sharing between public and private organizations. By promoting the development of a single window, enabled via standardized interfacing technologies between agency specific IT applications, netcentric information orchestration fosters the existing technology diversity. We assert that we only need to abandon diversity for uniformity when we have found the single best way to share information in PSNs.

### Evaluation cycle: prototyping and gaming-simulation
The final cycle in this research focused on the evaluation of our design theory (i.e., the design principles for network centric information orchestration). The question leading this cycle asked to what extent the proposed design principles assure higher levels of IQ and SQ for relief workers when compared to existing hierarchical architectures. We evaluated the design principles in two stages. The first stage was to evaluate the technical feasibility of netcentric information orchestration. For evaluating the technical feasibility, we developed a prototype. We called this prototype DIOS (Disaster Information Orchestration System). We developed two versions of DIOS in this research. First, we developed DIOS 1.0 system, a Wiki-based online application embodying the design principles listed in Chapter 6. DIOS 1.0 had a number of technology-enabled features not found in version 2.0, such as logging in and out, a personalization of the functionalities visible to each role and partial implementation of Google Maps. However, a major disadvantage of DIOS 1.0 was that this system used full-page refreshing. Consequently, the web application refreshed completely every 30 seconds. The user-experience was therefore relatively poor. Because of the full-page refreshing issue and the database failure during the pretest with master students, we decided to redevelop DIOS and make version 2.0. Consequently, the main difference between DIOS 1.0 and 2.0 is that refreshing (presenting updated information fields) occurs seamlessly by using AJAX technology. The user does not see a whole page refresh, only parts of the page (e.g. one table) are refreshed immediately when an update is posted. In addition, we decided that every

user sees the same screen as everyone else, thereby removing the personalization feature of DIOS 1.0. We made the choice to employ a single network wide situation report for shared situational awareness, where everyone has real-time access to the same information. Eventually it became clear that several trade-offs had to be made between a number of requirements (e.g. personalization vs. shared situational awareness) in order to have a stable netcentric information orchestration prototype. In the end, we preferred a stable and dependable prototype to a prototype that contains all of the possible functionalities.

The second stage of evaluation included a quasi-experimental gaming-simulation. The DIOS 2.0 prototype was an important prerequisite for this form of evaluation with end-users (i.e., professional relief workers). The game was set up as a quasi-experiment, including two rounds of gaming. The first round of gaming simulated existing hierarchy based information management (without the design principles). The second round simulated network centric based information orchestration (based on the principles embodied in DIOS). After a pre-test with 24 master students, we conducted this quasi-experimental gaming-simulation with 24 professional relief workers. During the gaming-simulation, we collected qualitative data (based on observations and video recording) and quantitative data using surveys. The qualitative data collected from the two rounds of gaming revealed several advantages and weaknesses of netcentric information orchestration compared to hierarchical information management. Relief workers were more relaxed and yet quicker in their information management activities using the DIOS prototype. On the other hand, we observed situations in which relief workers made decisions outside their mandate, just because they had the ability to do so in DIOS. Stanovich (2006) had already warned us for this type of 'renegade freelancing'. We have also observed some difficulties in dealing with so much information in a single window and heard request for more agency and role specific information displays. Moreover, we also observed a low level of IT-readiness (defined as the willingness and ability to employ IT for tasks execution) amongst the participants, something we have also seen throughout our field studies. In addition, some of the participants were locked-in their current practices and had difficulties in embracing any solutions that might modify their known (and trained) practices. While the low level of IT-readiness may be a non-issue for future generations of relief workers, we are more concerned about the observed professional culture of the relief workers towards information sharing in a network setting. When we consider the quantitative data, most average IQ and SQ scores provided by the relief workers were higher for netcentric information orchestration than hierarchical information management. However, a test of the statistical significance of the apparent differences between both information system architectures requires us to interpret the quantitative results more carefully. When adhering to such strict rules for statistical significance, we can say that regarding the IQ, netcentric information orchestration assures higher IQ-correctness and IQ-timeliness, SQ- accessibility and SQ-response time.

# Samenvatting (summary in Dutch)

## Inleiding

Recente rampen over de gehele wereld hebben opnieuw aangetoond dat informatiemanagement in publieke veiligheidsnetwerken (Public Safety Networks, PSN) een probleem is. Informatiemanagement, gedefinieerd als een cyclus van informatieverzameling, opslag, validatie, verrijking en verspreiding vindt veelal nog monodisciplinair (hulpdienst specifiek) en langs hiërarchische lijnen plaats. De huidige, op hiërarchie gebaseerde informatiesystemen die het informatiemanagement proces moeten ondersteunen falen vooral in het waarborgen van de informatiekwaliteit (Information Quality, IQ) voor hulpverleners. Als gevolg hiervan nemen hulpverleners vaak cruciale beslissingen op basis van onjuiste, onvolledige en verouderde informatie. Daarnaast hebben rampen zoals de Polderbaan crash in 2008 laten zien dat de kwaliteit van de huidige informatiesystemen (System Quality, SQ) niet op orde is. Bovendien tonen evaluatieverslagen een aantal voorbeelden van lage SQ aan, zoals hoge responstijden, beperkte toegang tot benodigde informatie en inflexibele informatiestromen. Vaak worden de lage IQ en SQ toegeschreven aan de kenmerken van rampen (complex en onvoorspelbaar) en de aard van veiligheidsnetwerken (veel actoren met onzekere informatie behoeften). In dit onderzoek behandelen we IQ en SQ niet als problemen, maar als symptomen van gebrekkige informatiesystemen.

Los van enkele theoretische paden, biedt de bestaande literatuur echter weinig begeleiding aan belanghebbenden (informatiesysteem architecten, beleidsmakers en softwareleveranciers) bij het waarborgen van de IQ en SQ tijdens rampen. Dit proefschrift beoogt daar verandering in te brengen. Het doel is om te onderzoeken welke ontwerpprincipes voor informatiesystemen een hogere mate van IQ en SQ kunnen waarborgen dan de huidige, op hiërarchie gebaseerde informatiesystemen. Door het gebruik van de design science onderzoeksstrategie is dit onderzoek ingedeeld in vier cycli: een relevantiecyclus (gebruikmakend van veldonderzoek), een theoriecyclus (gebruikmakend van paden in bestaande theorieën), een ontwerpcyclus (combineren van empirische en theoretische inzichten) en een evaluatiecyclus (aan de hand van een prototype en een quasi-experimentele spelsimulatie met hulpverleners). De ontwerpcyclus integreert de bevindingen van de relevantiecyclus en de theoriecyclus tot een ontwerptheorie: netcentrische informatie-orkestratie, bestaande uit een tiental ontwerpprincipes. De evaluatiecyclus laat zien dat netcentrische informatie-orkestratie een hogere mate van IQ en SQ waarborgt voor hulpverleners dan traditionele (hiërarchie gebaseerde) informatiesystemen.

## De horden voor het waarborgen van IQ en SQ in de veiligheidsketen

Tijdens de rampenbestrijding moeten opeens tal van openbare en particuliere organisaties samenwerken als één veiligheidsnetwerk. Deze vorm van samenwerking is nodig aangezien geen enkele hulpdienst of private organisatie over alle middelen en expertise beschikt om de diverse aspecten van een ramp te kunnen beheersen. Rampenbestrijding is voor geen enkele organisatie een primair proces of een kerntaak, rampen komen immers niet vaak voor. Met de focus op het ondersteunen van de interne en dagelijkse processen, hebben hulpdiensten hun eigen informatiesys-

temen ontwikkeld. Deze informatiesystemen zijn vaak niet flexibel en niet bedoeld om informatiebehoeften te ondersteunen die buiten de grenzen van de eigen hulpdienst vallen. Naarmate de omvang en ernst van een ramp toeneemt, ontvouwen PSN's zich in drie echelons: strategisch, tactisch en operationeel. In overeenstemming met deze hiërarchische gezagsstructuur worden verschillende mono- en multidisciplinaire crisisteams geactiveerd. De output van deze teams omvat besluiten en acties, terwijl de input voor deze teams een situatie afhankelijke mix van informatie, protocollen en gebeurtenissen omvat. In veel gevallen worden inter-organisatorische- en inter-echelon informatiemanagement processen beperkt door de mogelijkheden en capaciteiten die door de afzonderlijke (hulpdienst specifieke) informatiesystemen worden geboden. Daarnaast zijn er nog andere belemmeringen die bij het bestuderen van de sociale en technische componenten van informatiesystemen naar voren komen.

Ten eerste heeft elke hulporganisatie haar eigen specialisatie en daarbij horende informatiebehoefte. In de praktijk zijn de informatiesystemen van de verschillende hulporganisaties onverenigbaar, waardoor informatiemanagement tussen organisaties en tussen bestuurlijke lagen lastig is. Ten tweede is vraag en aanbod van informatie verspreid over het netwerk en moeilijk vooraf te bepalen. Een hulpverlener kan op tijdstip t=0 zowel een bron als een afnemer van informatie zijn. Tenslotte maakt de onzekerheid die inherent is aan rampen het moeilijk om vooraf vast te stellen welke informatiestromen zullen optreden en welke informatiebehoefte zich zal manifesteren gedurende een ramp. Aangezien de informatiesystemen van de individuele hulporganisaties zijn ontworpen om dagelijkse processen op organisatorisch niveau te ondersteunen, bieden deze slechts beperkte ondersteuning aan informatiemanagement op een multidisciplinair (netwerk) niveau.

## Onderzoeksvraag en onderzoeksstrategie

Aangezien er geen rechtstreeks toepasbare theorieën zijn voor het waarborgen van IQ en SQ tijdens een crisisrespons, volgt dit proefschrift een design science onderzoeksstrategie. Design science onderzoek is ingegeven door de wens om de maatschappij te verbeteren met behulp van nieuwe en innovatieve artefacten. Deze aanpak stelde ons in staat om dit onderzoek te starten vanuit een eerste vermoeden over een mogelijke oplossing. Ons eerste vermoeden was dat de louter samenvoeging van afzonderlijke, hulpdienst-specifieke informatiesystemen tijdens een crisis onvoldoende mogelijkheden biedt voor het waarborgen van IQ en SQ in een netwerk van publieke en private organisaties. Daarnaast suggereerden de coördinatietheorie en de Network Centric Operations (NCO) theorie al aan het begin van dit onderzoek een aantal theoretische paden waarlangs ontwerpprincipes voor IQ en SQ konden worden afgeleid. Op basis van dit eerste vermoeden, formuleerden we de centrale onderzoeksvraag als: voortbordurend op de coördinatietheorie en de NCO-theorie, welke ontwerpprincipes waarborgen een hogere IQ en SQ tijdens een crisisresponse? Deze hoofdvraag valt uiteen in een viertal deelvragen, waarbij iedere deelvraag leidend is bij één van de design science cycli. We vatten vervolgens de bevindingen van elke cyclus samen.

## De theoriecyclus: het meten en waarborgen van IQ en SQ

Voorafgaand aan de relevantiecyclus hebben wij in de theoriecyclus literatuuronderzoek verricht naar instrumenten voor het meten van IQ en SQ. Daarnaast hebben wij de coördinatietheorie en de NCO-theorie verder onderzocht voor paden in

de relevantiecyclus en ontwerpcyclus die gevolgd kunnen worden voor het afleiden van ontwerpprincipes. De deelvraag die leidend was in de theoriecyclus is tweeledig: (1a) welke instrumenten worden in de literatuur aangereikt voor het meten van IQ en SQ?, en (1b) welke paden worden in de coördinatietheorie en de NCO theorie beschreven voor het waarborgen van IQ en SQ?

Het antwoord op vraag 1a bestaat uit een tweetal raamwerken die elk instrumenten bevatten waarmee wij IQ en SQ kunnen meten. Uit de literatuur valt op te maken dat IQ en SQ multi-dimensionele constructen zijn die afhankelijk van de perspectief op informatie (als product of proces) langs verschillende dimensies en instrumenten kunnen worden geëvalueerd. Zowel de dimensies als instrumenten zijn al geëvalueerd in onderzoek van derden. Aangezien IQ en SQ subjectieve constructen zijn, is het van belang dat wij deze meten via de gebruiker van informatie, in dit geval de hulpverlener. De raamwerken met meetinstrumenten voortkomend uit de theoriecyclus waren noodzakelijk voor het starten van de relevantiecyclus.

Het antwoord op vraag 1b valt uiteen in een zevental theoretische paden, vier uit de coördinatietheorie en drie uit de NCO-theorie. De paden uit de coördinatietheorie zijn 'boundary spanning' (rollen en objecten over de grenzen van organisaties), orkestratie (afstemming van variëteit), 'advance structuring' (vooraf ontwikkelen van vaardigheden) en 'dynamic adjustment' (aanpassen van mogelijkheden gedurende een ramp). De paden uit de NCO-theorie zijn 'reachback' (direct toegang tot externe informatiebronnen), 'zelfsynchronisatie' (van individuen en groepen in een netwerk) en 'informatiepooling' (single window tot benodigde informatie). Hoewel deze paden een doelgerichte evolutie binnen de genoemde theorieën beschrijven, bieden deze paden afzonderlijk nog onvoldoende houvast voor het ontwikkelen van ontwerpprincipes. Om de mogelijkheden en beperkingen van deze paden in te kunnen schatten moet eerst de relevantiecyclus worden doorlopen.

### De relevantiecyclus: veldonderzoek en empirische data collectie

Uitgerust met de IQ en SQ meetinstrumenten uit de literatuur en bewust van de paden uit de theorie begonnen wij aan ons veldonderzoek. Het veldonderzoek vond plaats in drie Nederlandse regio's: Rotterdam-Rijnmond, Gelderland en Delfland. Deze regio's zijn geselecteerd op een aantal criteria, waaronder het gebruik van verschillende informatiesystemen gedurende een crisisrespons. Het veldonderzoek was bedoeld om de tweede onderzoeksvraag te beantwoorden. Deze vraag is driedelig. De eerste deelvraag (2a) luidt: op welke wijze wordt in de praktijk informatie gemanaged binnen en tussen multidisciplinaire teams? We stellen deze vraag om inzicht te krijgen in de rollen, taken, informatiestromen en informatietechnologie (IT) applicaties binnen de huidige informatiesystemen. Aangezien er geen uitgebreide beschrijvingen van informatiesystemen voor de crisisresponse bestaan in de huidige literatuur, hebben wij de vraag voornamelijk beantwoord aan de hand van observaties in de praktijk. In teams van één tot vier personen hebben wij ruim 22 verschillende crisisrespons-oefeningen geobserveerd. Observaties vonden plaats op basis van vooraf gedefinieerde observatieprotocollen. Deze observaties resulteerden in een drietal uitgebreide beschrijvingen van informatiesystemen voor crisisrespons. Opvallend is de verscheidenheid in rollen en IT applicaties die deel uitmaken van de huidige informatiesystemen. Onze waarnemingen tonen aan dat ondanks dat er langs meerdere kanalen (radio, emailberichten en digitale kaarten) informatie wordt gedeeld, de informatiestromen primair binnen de diensten en langs de hiërarchische lijnen plaatsvinden. Veel informatie wordt gedeeld volgens

een hiërarchisch georganiseerde commando- en controlestructuur. De informatie, die vaak versnipperd is over het gehele netwerk, wordt hierdoor onvoldoende geaggregeerd tot een gedeeld (multidisciplinair) beeld van de crisissituatie. Bovendien zijn de rollen en IT-applicaties voor inter-team en inter-echelon informatiemanagement gefixeerd op het opstellen van situatierapporten en bieden weinig mogelijkheden voor het waarborgen van IQ en SQ. Deze hiërarchie van informatie-uitwisseling resoneert met een functionele hiërarchie. Commandanten informeren hun officieren op een beperkte, 'need to know'-basis en zijn zich vaak niet bewust van de bredere context en betekenis van deze informatie voor de andere hulpdiensten.

Gelet op de verscheidenheid aan informatiesystemen in de praktijk ontstaat de tweede deelvraag (2b): welke niveaus van IQ en SQ worden gewaarborgd door de huidige informatiesystemen? We onderzochten deze vraag met behulp van enquêtes. De enquêtes bestaan uit IQ en SQ stellingen die zijn getoetst in eerdere studies. De verzamelde onderzoeksgegevens zijn gecodeerd en geanalyseerd met behulp van SPSS (een software applicatie voor geavanceerde kwantitatieve data-analyse). Na een controle op de volledigheid en betrouwbaarheid van de 177 ingevulde enquêtes, bleven 153 over voor data-analyse. De data-analyse resulteert in de volgende conclusies. Het op één IT-applicatie gebaseerde informatiesysteem in Rotterdam-Rijnmond scoort volgens de geënquêteerde hulpverleners hoog op IQ-consistentie, IQ-relevantie en IQ-correctheid, maar laag op IQ-tijdigheid, SQ-toegankelijkheid en SQ-responstijd. In Gelderland observeerden we de effecten van het gebruik van meerdere (vier) IT-applicaties voor informatiemanagement. Dit op multi-applicatie gebaseerde informatiesysteem scoort volgens de geënquêteerde hulpverleners hoog op IQ-correctheid, IQ-relevantie en IQ-actualiteit, maar laag op IQ-volledigheid, IQ-consistentie en SQ-toegankelijkheid. Tenslotte hebben wij in Delfland hulpverleners geënquêteerd over de IQ en SQ die wordt gewaarborgd bij het gebruiken van statusborden tijdens een crisisresponse. Dit niet IT-gebaseerde informatiesysteem scoort volgens de geënquêteerde hulpverleners hoog op IQ-correctheid, IQ-consistentie en IQ-relevantie, maar laag op IQ-volledigheid, SQ-responstijd en SQ-toegankelijkheid.

De derde deelvraag (2c) gaat in op de bestaande best practices van informatiesysteem architecten als het gaat om het waarborgen van IQ en SQ. Deze vraag werd gesteld, omdat we ervan overtuigd waren dat informatiesysteem architecten niet alleen een beter begrip van de bestaande informatiesystemen hebben als wij, maar ook omdat de architecten een goede jury vormden voor de mogelijkheden en beperkingen van de theoretische paden die wij uit de literatuur hebben afgeleid. We onderzochten deze vraag aan de hand van interviews met zestien senior informatiesysteem architecten die werkzaam zijn voor verschillende hulporganisaties in Nederland. Na het uitvoeren van de interviews en het controleren van de transcripten met de geïnterviewde architecten, hebben we de transcripten gecodeerd en geanalyseerd met behulp van ATLAS.ti (een software applicatie voor geavanceerde kwalitatieve data-analyse). De interviewresultaten laten zien dat op dit moment SQ, met name het creëren van interoperabiliteit tussen diverse databases, een hogere prioriteit geniet dan het waarborgen van IQ. Hoewel de architecten het belang van IQ ook beamen, vinden zij het waarborgen van IQ een zorg voor de toekomst. Tenslotte stellen de architecten dat er geen nationaal gedragen principes bestaan voor het ontwerpen van informatiesystemen voor een crisisrespons. Ontwikkelingen op het gebied van NCO en 'service oriented architectures' (SOA) zijn

volgens de architecten de trends die het landschap van informatiesystemen zullen bepalen.

**De ontwerpcyclus: netcentrische informatie-orkestratie als ontwerp-theorie**

Voortbouwend op de resultaten van de theorie- en relevantiecyclus, zijn wij begonnen aan de ontwerpcyclus in dit onderzoek. De vraag die wij in deze cyclus beantwoorden is, welke ontwerpprincipes kunnen een hogere IQ en SQ waarborgen tijdens een crisisresponse? Deze deelvraag levert de belangrijkste theoretische bijdrage van dit proefschrift. Ons doel was om ontwerpprincipes te synthetiseren, die na toepassing een hogere mate van IQ en SQ waarborgen dan de bestaande, op hiërarchie gebaseerde informatiesystemen. Na de integratie van de paden uit de theorie-en (coördinatietheorie en NCO) en onze veldstudie bevindingen pleiten wij voor een meer gedecentraliseerde en real-time gedreven vorm van inter-agency en inter-echelon informatiemanagement tijdens een cisisrespons. We noemen deze aanpak netcentric informatie-orkestratie en werken deze uit als een ontwerptheorie bestaande uit een tiental ontwerpprincipes, waaronder 'hergebruik informatie', ontwikkel een netwerk informatie pool als situatie-overzicht' en 'ontwikkel functionaliteiten voor het beoordelen van informatie'.

Netcentric informatie-orkestratie vraagt om de ontwikkeling van netwerkbrede orkestratie mogelijkheden voorafgaand aan (advance structuring) en tijdens een crisisrespons (dynamic adjustment). Vooraf structureren bevordert het maximaliseren van 'reachback' mogelijkheden en diversificatie van informatiebronnen voor datatriangulatie. Dit traject resulteert in preventieve en beschermende maatregelen voor het structureren van de organisatie onder informatiestromen. Dynamische structureren bevorderen onder andere het proactief scannen van interne-en externe informatiebronnen (zoals Twitter en Youtube) en het continu reflecteren op de kwaliteit van de gedeelde informatie. Netcentric informatie-orkestratie vraagt om een gedreven herinrichting van de bestaande, op hiërarchie gedreven informatiesystemen waarbij hulpverleners worden versterkt (empowered) in hun vermogen om zichzelf van de meest recente en gevalideerde informatie te voorzien. Deze herinrichting is schaalbaar, aangezien meerdere orkestratoren kunnen worden geactiveerd naarmate de omvang van de crisis toeneemt.

Netcentric informatie-orkestratie zorgt ervoor dat de huidige diversiteit (verschillende IT-applicaties) in de bestaande PSN's niet verloren gaat (in tegenstelling tot het verplichten van één IT-applicatie voor alle hulpdiensten). Door moderne technologie standaarden zoals XML te gebruiken, kunnen informatie objecten uit diverse IT-applicaties en databases worden geput zonder dat de applicaties een directe koppeling met elkaar moeten hebben. Via orkestratie proberen we de variëteit te benutten in de verschillende informatiesystemen die momenteel gebruikt worden in de verschillende PSN's. Variëteit verwijst hier naar de verschillende, soms overlappende softwareapplicaties, rollen, objecten en procedures. In tegenstelling tot uniformiteit ('one size fits all' informatiesysteem), waarborgt variëteit het ondersteunen van een ruimer informatieaanbod tijdens onvoorspelbare rampen. Wij zijn van mening dat het pad van variëteit alleen dan moet worden verlaten zodra de beste manier om informatie te delen is gevonden. Onze analyse van de literatuur laat zien dat de huidige informatiesystemen vooral zijn ontwikkeld om routinematige processen binnen de hiërarchie van de eigen hulpverleningsorganisaties te ondersteunen. Deze op hiërarchie gebaseerde informatiesystemen voldoen

vaak aan de informatiebehoefte tijdens normale, dagelijkse omstandigheden (geen crisis). Deze informatiesystemen kunnen echter de netwerk brede en onvoorspelbare informatiebehoefte die ontstaat tijdens multidisciplinaire rampenbestrijding onvoldoende ondersteunen, met als gevolg dat hulpverleners actie moeten ondernemen op basis van informatie die onjuist, niet compleet of verouderd is. In plaats van het volledig opgeven van de huidige informatiesystemen, biedt orkestratie de mogelijkheid om de huidige informatiesystemen te versterken met een specifieke reeks van dynamische capaciteiten die nodig zijn voor het waarborgen van IQ en SQ. Deze zogenaamde 'dynamic capabilities' zijn onder andere: netwerk brede toegang tot informatie, real-time informatie-uitwisseling en informatiewaardering aan de hand van kwaliteitsfeedback.

### De evaluatiecyclus: orkestratie prototype en quasi-experiment

De laatste cyclus van dit onderzoek omvatte de evaluatie van de ontwerptheorie (de ontwerpprincipes voor netcentrische informatie-orkestratie). We evalueerden de ontwerptheorie in twee opeenvolgende stappen. Allereerst evalueerden wij de technische realiseerbaarheid van de ontwerpprincipes door middel van een prototype. De constructie van het prototype, een online 'single window' IT-applicatie, werd geleid door de principes van netcentrische informatie-orkestratie. Daarnaast was het prototype ook nodig om later de ontwerpprincipes samen met hulpverleners te evalueren in een spel. Dit prototype heet DIOS (Disaster Information Orchestration System) en moest ervoor zorgen dat informatie tussen verschillende hulpdiensten, multidisciplinaire teams en echelons kon worden gedeeld via het internet. De eerste versie van dit prototype (DIOS 1) werd gerealiseerd in een online, Wikipedia-achtige omgeving die gebruikers de mogelijkheid bood om informatie uit diverse interne- en externe databases te verzamelen op basis van web-services. DIOS 1 faalde echter bij een proefspelsimulatie met studenten. Op basis van de waargenomen beperkingen van DIOS 1 (o.a. een beperkte database en hoge screen refresh rate), zijn we gestart met het ontwikkelen van DIOS 2. De tweede versie van DIOS is ontwikkeld als een Dashboard met daarin uitklapbare informatievelden die dankzij AJAX-technologie en een SQL-database het scherm niet steeds ververste bij het binnenkomen van nieuwe informatie. Een stresstest laat zien dat DIOS 2 niet faalt bij het simultaan gebruik over het internet. DIOS 2 toont dat de ontwerpprincipes in ieder geval technisch realiseerbaar zijn.

Naast de technische realiseerbaarheid, omvatte de evaluatiecyclus ook een evaluatie van de ontwerpprincipes met hulpverleners uit de praktijk. De deelvraag die hierbij centraal staat is in welke mate netcentrische informatie- orkestratie leidt tot het beter waarborgen van IQ en SQ vergeleken met een op hiërarchie gebaseerde informatiesysteem. Deze deelvraag werd onderzocht door middel van een spelsimulatie (rollenspel) met hulpverleners. Deze spelsimulatie is opgezet als een quasi-experiment met twee spelronden. In de eerste spelronde gebruikten de hulpverleners een op hiërarchie gebaseerd informatiesysteem voor het management van informatie gedurende een fictieve ramp. In de tweede spelronde gebruikten dezelfde hulpverleners het DIOS prototype voor netcentrische informatie-orkestratie gedurende een fictieve ramp. Door de spelsimulatie op te zetten als quasi-experimenten, kunnen wij de verzamelde data over beide spelronden vergelijken. In totaal hebben 24 hulverleners van verschillende organisaties deelgenomen aan ons spel. Deze spelsimulatie werd eerder al gespeeld met studenten om zodoende te toetsen of de verschillende elementen van de spelsimulatie (scenario's, rolbeschrij-

vingen, berichten etc.) duidelijk en uitvoerbaar waren. Na de pre-test met 24 studenten, voerden we deze quasi-experimentele spelsimulatie met 24 professionele hulpverleners. Tijdens de spelsimulatie met hulpverleners, verzamelden we kwalitatieve gegevens (gebaseerd op observaties en video-opname) en kwantitatieve gegevens met behulp van enquêtes.

De kwalitatieve gegevens die wij hebben verzameld over de twee spelrondes onthullen een aantal voordelen en zwakke punten van netcentrische informatie-orkestratie in vergelijking met hiërarchisch informatiemanagement. Hulpverleners waren meer ontspannen en sneller in hun informatiemanagement activiteiten via het DIOS prototype. Aan de andere kant hebben we situaties waargenomen waarin hulpverleners beslissingen namen buiten hun mandaat, omdat ze in DIOS hiertoe de mogelijkheid kregen dit te doen. Literatuur op NCO had al gewaarschuwd voor deze vorm van 'renegade freelancing'. We hebben ook gezien dat enkele hulpverleners aan het begin van de tweede ronde wat moeite hadden met de relatief grote hoeveelheid aan informatie in een informatiesysteem. We kregen tevens enkele verzoeken om de informatie in DIOS beter te clusteren naar de specifieke rollen en hulpdiensten die van het informatiesysteem gebruik kunnen maken. Tenslotte hebben een tweetal hulpverleners ook zorgen geuit over de implementatie van dit soort systemen in de praktijk, mede omdat deze niet in lijn was met hun voorgaande training en procedures.

Wanneer we de kwantitatieve gegevens overwegen, blijkt dat netcentrische informatie-orkestratie hoger scoort over bijna alle IQ en SQ variabelen dan het geval bij hiërarchisch informatiemanagement. Alleen de gemiddelde waarden voor IQ-consistentie en IQ-relevantie waren lager voor netcentrische informatie-orkestratie. Echter, een test naar het statistische significantie van de kwantitatieve verschillen tussen beide informatiesystemen noodzaken ons om deze resultaten met enig voorbehoud te interpreteren. Zelfs bij het naleven van dergelijke strenge regels voor statistische significantie kunnen we concluderen dat netcentrische informatie-orkestratie leidt tot het beter waarborgen van IQ-correctheid, IQ-actualiteit, SQ-toegankelijkheid en SQ-response-tijd.

**Conclusies en aanbevelingen**

Dit proefschrift introduceert: 'Netcentrische informatie-orkestratie', een ontwerptheorie voor het waarborgen van IQ en SQ tijdens multidisciplinaire rampenbestrijding. Deze ontwerptheorie bestaat uit een tiental ontwerpprincipes, die gestoeld zijn op theoretische paden en empirische inzichten. De ontwerpprincipes zijn in dit proefschrift getoetst op technische realiseerbaarheid (in een prototype) en de mate waarin zij bijdragen aan het waarborgen van de IQ en SQ voor hulpverleners (aan de hand van een quasi-experimentele spelsimulatie met hulpverleners). Het quasi-experiment laat zien dat netcentrische informatie-orkestratie een hogere mate van IQ en SQ waarborgt voor hulpverleners dan traditionele (hiërarchie gebaseerde) informatiesystemen. Door op basis van de tien aangereikte ontwerpprincipes informatie te orkestreren tussen multidisciplinaire teams en tussen coördinatielagen, krijgen hulpverleners sneller de juiste informatie die zij nodig hebben voor het uitvoeren van hun taken. Dit onderzoek reikt zes aanbevelingen voor vervolgonderzoek aan.

De eerste aanbeveling is om vervolgonderzoek te verrichtten naar instrumenten die helpen in het aanpassen van de huidige houding van hulpverleners jegens netwerk gebaseerde informatiesystemen. Om daadwerkelijk de voordelen van

netcentrische systemen te kunnen benutten, is het van belang dat hulpverleners begrijpen dat zij niet alleen lid zijn van een hulpdienst, maar tevens een bron zijn van informatie in een netwerk van publieke en private organisaties. Een tweede aanbeveling is om vervolgonderzoek te verrichten naar het proactief benutten van media- en burgerinformatie. Ondanks het feit dat hulpverleners zich vaak bewust zijn van de waarde van media- en burgerinformatie, bieden huidige informatiesystemen te weinig middelen om deze informatie gevalideerd en tijdig te kunnen benutten. Hoewel het DIOS prototype hulpverleners toegang biedt tot informatie in sociale netwerken zoals Twitter en Youtube, benutten wij tot dusver slechts een fractie van de potentie die dit soort participatieve en interactieve platformen te bieden hebben. Een derde aanbeveling is om vervolgonderzoek te verrichten naar het voorkomen van 'renegade freelancing'. Dit zijn situaties waarbij hulpverleners beslissingen nemen die buiten hun bevoegdheden vallen en niet in lijn zijn met de doelstellingen van de besluitvormers. Hoewel 'renegade freelancing' ook plaatsvindt in op hiërarchie gebaseerde informatiesystemen, liet het quasi-experiment ons zien dat onbegrensde toegang tot informatie de kans op dit fenomeen versterkt. Een vierde aanbeveling is om vervolgonderzoek te verrichten naar simpele doch robuuste systemen waarop hulpverleners kunnen terugvallen, indien ICT hen in de steek laat.

Ondanks het feit dat ICT infrastructuren steeds minder uitval vertonen en er veel onderzoek wordt verricht naar het voorkomen van infrastructuur falen, zijn er nog situaties denkbaar waarbij hulpverleners moeten terugvallen op systemen gebaseerd op pen en papier voor het delen van informatie. Tot dusver is er weinig onderzoek verricht naar wanneer en hoe terug te vallen op pen en papier systemen gedurende rampen. Een vijfde aanbeveling is om vervolgonderzoek te verrichten naar het verbergen van de adaptiviteit in ICT. Waar er nog veel onderzoek wordt gedaan naar ICT systemen die zich automatisch kunnen aanpassen aan de omgeving en behoefte van gebruikers gedurende een ramp, hebben wij herhaaldelijk het verzoek gekregen van hulpverleners om systemen te ontwikkelen die voor hen bekend zijn. De uitdaging voor verder onderzoek is om de gebruikersinterface (presentatie laag) van systemen zo stabiel mogelijk te houden, terwijl de achterliggende techniek zich aanpast aan de veranderende situatie. Tenslotte stelt dit proefschrift dat er verder onderzoek nodig is naar het op de 'juiste' manier gebruiken van informatie gedurende een rampenbestrijding. Waar de betrokken partijen vaak streven naar 'het delen van de juiste informatie, op het juiste moment en tussen de juiste personen', is er nog weinig onderzoek verricht naar voorschriften voor het op de juiste manier gebruiken van informatie in een netwerk van organisaties.

# Appendices

## *Appendix A: List of abbreviations*

| | |
|---|---|
| AJAX | Asynchronous Javascript And XML |
| ARB | Ambternaar Rampenbestrijding |
| BW | Brandweer (fire department) |
| COPI | Commando place incident team |
| DCMR | Dienst Chemische stoffen en Milieu Rijnmond |
| ECR | Emergency Control Center |
| GHOR | Geneeskundige Hulpverlening bij Ongevallen en Rampenbestrijding |
| GIS | Geographic information systems |
| GMS | Gemeenschappelijk Meldkamer Systeeem |
| GRIP | Coordinated incident response procedure |
| GVS | Gemeentelijke Veiligheids Staf/Municipal Crisis Center (MCC) |
| HCC | Harbor Coordination Center |
| HHD | Hoogheemraadschap Delfland |
| IC | Information Coordinator |
| ICT | Information & Communication Technology |
| IM | Information Manager |
| IQ | Information Quality |
| IS(s) | Information System(s) |
| IT | Information Technology |
| KMNI | Koninklijk Nederlands Meteorologisch Instituut |
| NCO | Network Centric Operations |
| POR | Port of Rotterdam |
| PSN | Public Safety Network |
| ROT | Regional Operational Team |
| RPA | Rotterdam Port Authority |
| SD | Standard Deviation |
| Sitreps | Situation reports |
| SOA | Service Oriented Architecture |
| SQ | System Quality |
| XML | Extensible Markup Language |

## *Appendix B: Field study protocol*

**Name of the observer**: ..........................
**Exercise/game time and location:**
**Observed team:** □ ROT/RBT    □ COPI    □ GVS    □ Field-units    □ ECC
**Number of participants observed:**

| General | Description |
|---|---|
| Information management roles, tasks and responsibilities | (describe the roles, tasks and responsibilities regarding information management) |
| Command structure | (describe the authority and formal command scheme within and between echelons and teams) |
| Information needs | (describe the request for information via information systems) |
| Information ownership | (describe the information objects the different agencies and teams possess) |
| Information flows | (describe which roles, teams and agencies exchange information the direction of information flows) |
| Information technology | (describe the software applications, functionalities, hardware devices etc.). |
| **Information Quality** | **Description** |
| Correctness (e.g., wrong location or incorrect number of casualties) | Time:......... |
| Completeness (e.g., no info about the flamability of a gas) | Time:......... |
| Timeliness (e.g., info response contains info that is outdated) | Time:......... |
| Relevance (e.g., info that is not useful for the receiving person/team) | Time:......... |
| Consistency (e.g., persons or teams work with different info about the situation) | Time:......... |
| Amount (e.g., too much or too little info about the incident or location) | Time:......... |
| **System quality** | **Description** |
| Accessibility (e.g., to location info and information from private/secured data sources) | Time:......... |
| Response time (e.g., delays between info request and response) | Time:......... |
| Reliability (e.g., system failure, downtime, incorrect responses etc.) | Time:......... |
| Flexibility (e.g., changed screens, scenario specific functionalities) | Time:......... |
| Ease of use (e.g., difficulties in log-in and navigation) | Time:......... |

## Appendix C: Interviewees

The following table provides an overview of the interviewed information system architects. Only their first name of each respondent is listed in order to maintain anonymity.

**Table Appendix C-1: Overview of interview respondents**

| Id | Respondent | Organization | Background/expertise |
|---|---|---|---|
| 1 | Wim | Police | Former police squad commander, current head of the multi-agency disaster response training department |
| 2 | Anton | Rotterdam Port Authority | Emergency control room systems, communication technologies |
| 3 | Peter | Geo-technology provider | Geographic information technologies for disaster management |
| 4 | Daan | Port Authority | Port-officer squad commander |
| 5 | Leo | Ministry of Internal Affairs and Kingdom Relations, Department of Safety and Crisis Management | Development and implementation of advanced disaster management technologies, Network Centric Operations expert |
| 6 | Ralph | Chemical services | Chemical materials, codes, standards and technologies. |
| 7 | Vincent | Fire department | Fire squad manager, information management |
| 8 | Ton | Ambulance Services | Ambulance tracking systems, victim monitoring systems |
| 9 | Willem-Jan | Fire department | ICT support, organisational information-sharing |
| 10 | Martijn | Hazmat services | Hazardous materials registration, risk communication and data sharing |
| 11 | Sander | Police | Information architectures, application manager |
| 12 | Mark | Ambulance | Information management |
| 13 | Leo | Police | ICT architect, registration systems |
| 14 | Marcel | Fire department | Information management |
| 15 | Kees | Infrastructure services | Disaster displays, communication systems architect |
| 16 | Jan-Willem | Application provider | Crisis response systems, service-oriented architectures |

## *Appendix D: Survey questions*

In this appendix, the surveys used in this research are presented. The items in the survey are in Dutch. Note that the survey used for gaming-simulation included all parts, while only parts C, D and F were included in the surveys for the field studies.

Beste respondent,
Wij willen u vragen om deze vragenlijst invullen, als onderdeel van deze spelronde. De resultaten van deze vragenlijst zullen alleen worden gebruikt voor verder weten-schappelijk onderzoek naar de knelpunten voor informatie- en systeemkwaliteit tijdens rampenbestrijding. Alvast bedankt voor het willen invullen van de vragen-lijst!

**Deel A. Algemene vragen**

1. Voor welke organisatie werkt u?
□ a. Brandweer             □ d. Politie
□ b. Gemeente             □ e. Waterschappen
□ c. GHOR                □ f. Anders,namlijk..........................

2. Hoeveel jaar werkt u al voor deze organisatie?
□ a. 0 tot 1 jaar               □ d. 5 tot 10 jaar
□ b. 1 tot 3 jaar               □ e. 10 tot 20 jaar
□ c. 3 tot 5 jaar               □ f. meer dan 20 jaar

3. In welke van de volgende teams heeft u in de praktijk deelgenomen?
□ a. Regionale Beleids Team          □ d. Gemeentelijke Veiligheidstaf
□ b. COPI (COmmando Plaats Incident)      □ e. Meldkamer
□ c. Veld                       □ f.Anders, namelijk

4. Hoe vaak hebt u al meegedaan tijdens een daadwerkelijke GRIP situatie in de praktijk (GRIP 1 en hoger)?
□ a. 0 keer                   □ d. 10 tot 15 keer
□ b. 1 tot 5 keer               □ e. 15 tot 20 keer
□ c. 5 tot 10 keer              □ f. meer als 20 keer

5. In welke van de volgende teams nam u deel gedurende het spel?
□ a. COPI (COmmando Plaats Incident)      □ e. Veld - GHOR
□ b. GVS (Gemeentelijke Veiligheidsstaf)   □ f. Meldkamer - Brandweer
□ c. Veld - Brandweer              □ g. Meldkamer - Politie
□ d. Veld- Politie                □ h. Meldkamer –GHOR

## Deel B. Evaluatie van de eerste spelronde

De volgende vragen betreffen de eerste spelronde en zijn geformuleerd als stellingen. In hoeverre bent u het eens met de volgende stellingen?

| | Totaal Oneens | | (omcirkel uw keuze) | | | Totaal Eens | |
|---|---|---|---|---|---|---|---|
| 1. De eerste spelronde was goed georganiseerd. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2. Het scenario van de eerste spelronde was realistisch. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 3. De structuur (volgorde) van de eerste spelronde was duidelijk. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 4. Ik kon op basis van mijn rolbeschrijving mijn taken in het spel goed vervullen. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 5. Mijn rolbeschrijving in het spel komt overeen met mijn dagelijkse rol. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 6. Mijn spelersboekje gaf mij voldoende informatie voor het kunnen deelnemen aan de eerste spelronde. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 7. Het gebruiken van Sitraps om informatie te delen tussen de verschillen teams komt overeen met de werkelijkheid. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 8. De afhankelijkheden tussen de deelnemende teams werd conform de realiteit in het spel nagespeeld. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 9. De organisatoren hebben op een realistische wijze de informatie uitwisselingsprocessen tijdens crisissituaties gesimuleerd. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 10. Over het algemeen was de eerste spelronde leerzaam. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

## Deel C. Evaluatie van de informatiekwaliteit
Tijdens de eerste ronde van het spel heeft u aan de hand van situatie rapporten informatie van anderen ontvangen en informatie naar anderen verstuurd. U kunt de kwaliteit van de ontvangen informatie bepalen aan de hand van verschillende informatie kwaliteit dimensies, zoals de juistheid, volledigheid en tijdigheid. In hoeverre bent u het eens met de volgende stellingen omtrent de informatie kwaliteit tijdens de eerste spelronde?

| | Totaal Oneens | (omcirkel uw keuze) | | | | | Totaal Eens |
|---|---|---|---|---|---|---|---|
| 1. Over het algemeen was de informatie die met mij werd gedeeld up-to-date. *<IQ timeliness1>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2. Over het algemeen was de informatie die met mij werd gedeeld correct. *<IQ correctness1>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 3. Over het algemeen was de informatie die met mij werd gedeeld volledig. *<IQ completeness1>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 4. Ik kreeg teveel informatie van de anderen. *<IQ overload1>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 5. De informatie die ik van anderen ontving was relevant (direct bruikbaar voor de uitvoering van mijn taken). *<IQ relevancy1>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 6. Die informatie die ik van anderen ontving was consistent (niet in tegenstelling tot de informatie die ik al had). *<IQ consistency1>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 7. De Kolom-sitrap bevatte verouderde informatie. *<IQ timeliness2>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 8. De Kolom-sitrap bevatte foutieve informatie. *<IQ correctness2>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 9. De Kolom-sitrap bevatte onvolledige informatie. *<IQ completeness2>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 10. Ik ontving onvoldoende (niet genoeg) informatie. *<IQ overload2>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 11. Door de steeds veranderende situatie ontving ik informatie die niet meer actueel was. *<IQ timeliness3>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 12. Veel van de informatie die ik had ontvangen was onjuist. *<IQ correctness3>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 13. Vaak ontbrak het nodige detail in die informatie die anderen met mij deelden. *<IQ completeness3>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 14. In verhouding met wat ik aan informatie nodig had was de hoeveelheid informatie die anderen met mij deelden te veel. *<IQ overload3>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 15. Ik ontving informatie die ik niet nodig had voor het uitvoeren van mijn taken. *<IQ relevancy2>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 16. Ik ontving overbodige informatie. *<IQ relevancy3>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 17. De informatie die ik had was inconsistent met de informatie van de anderen in mijn team *<IQ consistency2>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 18. Ik zou graag van anderen willen weten hoe betrouwbaar de informatie is die ze met mij delen. *<Func_ feedback 1>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 19. Het was voor mij onduidelijk of de informatie die ik had ontvangen betrouwbaar was. *<Func_feedback2>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 20. Ik had het gevoel dat de overige deelnemers over andere informatie beschikten dan ik *<IQ_consistency2>*. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

## Deel D. Evaluatie van de systeemkwaliteit

In de eerste ronde heeft u gebruik gemaakt van een hiërarchisch informatie systeem om informatie te kunnen ontvangen en delen. Dit informatie systeem valt te ontleden in een tweetal hoofdcomponenten: (1) formulieren, (2) een postbode (als vervanger voor C2000). U kunt u de kwaliteit van dit informatie systeem op basis van diverse kwaliteitsindicatoren beoordelen. In hoeverre bent u het eens met de volgende stellingen betreffende de systeemkwaliteit?

| | Totaal oneens | | (omcirkel uw keuze) | | | Totaal eens | |
|---|---|---|---|---|---|---|---|
| 1. Het informatiesysteem gaf mij onmiddellijk alle informatie die ik nodig had. *<SQ Responsetime1>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2. Via het informatiesysteem kon ik snel aan de informatie komen die ik nodig had. *<SQ_InfoAccesability1>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 3. Ik moest te lang wachten op informatie ik had aangevraagd. *<SQ Responsetime3>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 4. Ik kon rekenen op het informatiesysteem voor informatie. *<SQ reliability1>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 5. Het informatie systeem was eenvoudig te gebruiken. *(SQ Ease of use1)* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 6. Het informatiesysteem bood mij toegang tot informatie (bijv. opvanglocaties) die buiten het bereik van mijn organisatie ligt. *<SQ_InfoAccesability1* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 7. Via het informatie systeem had ik direct toegang tot de informatie die ik nodig had. *<Func_accesability2* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 8. Het informatiesysteem notificeerde mij indien veranderingen in de crisissituatie waren opgetreden *<Func_ eventNotification1>*. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 9. Dankzij het informatiesysteem had ik continu een totaal overzicht van alle informatie die ik nodig had. *<Func_ aggregation2>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 10. Veranderingen in basisinformatie (geo, meteo etc) waren onmiddellijk te zien in het informatiesysteem. *<Func_ eventNotification2>*. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 11. Het informatiesysteem gaf mij inzicht in de betrouwbaarheid van informatie. *<Func_ feedback 3>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 12. Het informatie systeem bood mij een geaggregeerd (totaal) beeld van de crisissituatie. *<Func_ aggregation1>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 13. Het informatie systeem liet real-time (onmiddellijk) de veranderingen in de crisissituatie zien *<Func_EventNotification3>*. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 14. Met dit informatie systeem was het eenvoudig om de geheugen (opgebouwde kennis van de situatie) te behouden *<Func_ Memory1>*. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 15. Met dit informatie systeem was het eenvoudig om foto's of andere kaartinformatie te delen *<Func_ Multi-mediaexchange>*. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 16. Met dit informatie systeem kon ik eenvoudig al mijn collega's (ook van de andere kolommen) van informatie voorzien <Func_Infosharing1> | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 17. Met dit informatie systeem kon ik eenvoudig al mijn collega's (ook van de andere kolommen) om informatie verzoeken. <Func_Infosharing2> | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 18. Ik ben tevreden over het huidige informatiesysteem. *<SQ_Satisfaction1>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 19. Ik vind het prima om dit hiërarchische informatiesysteem te blijven gebruiken in crisissituaties. *<SQ_Satisfaction2>* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

## Deel E. Evaluatie van de systeemfunctionaliteiten

DIOS kent enkele specifieke functionaliteiten die de informatiekwaliteit en systeemkwaliteit moeten waarborgen. Voorbeelden van deze functionaliteiten zijn het kunnen beoordelen van de informatie betrouwbaarheid en het opbouwen van een dynamische situatie beeld. In hoeverre bent u het eens met de volgende stellingen betreffende de systeemfunctionaliteiten?

| | | Totaal oneens | | (omcirkel uw keuze) | | Totaal eens | |
|---|---|---|---|---|---|---|---|
| 1. | De manier waarop informatie in DIOS is gecategoriseerd behoedt mij voor informatie overload (Func_category→IQ info amount) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2. | Het kunnen opzoeken van derde partij/externe informatie via DIOS versnelde het informatiedelings proces (Func_thirdparty1→info sharing speed) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 3. | Het dashboardoverzicht van laatst toegevoegde informatie in DIOS versnelde het informatiedelings proces (Func_dashboard→info sharing speed) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 4. | Met DIOS kon ik sneller informatie delen binnen mijn team (infosharingspeed_team level) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 5. | Met DIOS kon ik sneller informatie delen met mijn kolom (infosharingspeed_organizational level) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 6. | Doordat iedereen in het netwerk alle informatie in DIOS konden zien hadden wij sneller een gedeeld beeld van de situatie (Func_NetworkSitrap→ Situational Awareness) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 7. | Via DIOS zijn wij sneller gekomen tot een gedeeld beeld van de situatie (Situational Awareness) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 8. | Dankzij de vermelde betrouwbaarheid van de geplaatste informatie in DIOS konden wij als team sneller door de veelheid aan informatie (Funct_Rating→ IQ infosharingSpeed) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 9. | Ik zou graag de door anderen geplaatste informatie willen beoordelen op de betrouwbaarheid (Func_Rating) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 10. | De opgebouwde bibliotheek van informatie DIOS zorgde ervoor dat we geen belangrijke informatie kwijtraakten (Func_Memory→IQ relevancy) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 11. | De real-time veranderingen in de informatievelden van DIOS zorgen ervoor dat ik op de hoogte bleef van veranderingen in de crisis situatie (Funct_eventNotification → Situational awareness) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 12. | Met DIOS kon ik alle belangrijke informatie terugvinden. (Func_Memory) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

**Deel F.** Indien u nog andere suggesties of opmerkingen heeft naar aanleiding van de informatie- en systeemkwaliteit, kunt u die hieronder opschrijven.

Indien u een samenvatting van dit onderzoek wenst te ontvangen, kunt u hieronder uw e-mailadres opschrijven.

## *Appendix E: Publications by the author*

**2011**

- Bharosa, N., Janssen, M., & Tan, Y. (forthcoming). Netcentric information orchestration. *Journal of Cognition, Technology and Work*.
- Lee, J., Bharosa, N., Yang, J., Janssen, M. & Rao, H. (2011) Group value and intention to use — A study of multi-agency disaster management information systems for public safety. *Decision Support Systems*. 50 (2) pp. 404-414.
- Bharosa, N, Janssen, M., & Bajnath, S. (in press). Deriving Principles for Guiding Service Encounters: A Participative Design Research Approach. *International Journal of Information Systems in the Service Sector* (IJISSS).
- Bharosa, N., Janssen, M., Bajnath, S., Klievink, B., Overbeek, S. & van Veenstra, A.-F. (forthcoming) Service Delivery Principles: *Deriving Principles Using a Role-Playing Game*. The Electronic Journal of e-Government.

**2010**

- Bharosa, N., Janssen, M., Meijer, S., and Brave, F. (2010). Designing and Evaluating Dashboards for Multi-agency Crisis Preparation: A Living Lab. EGOV 2010, LNCS 6228, pp. 180–191 *(Paper nominated for "The most promising practical concept" Award)*.
- Bharosa, N., Bouwman, H. & Janssen, M. (2010). Ex-ante evaluation of disaster information systems: a gaming-simulation approach. *In Proceedings of the 7th International Conference on Information Systems for Crisis Response and Management (ISCRAM2010)*, Seatlle, USA.
- Bharosa, N., Meijer, S., Janssen, M. & Brave, F. (2010). Are we prepared? Experiences from developing dashboards for disaster preparation. *In Proceedings of the 7th International Conference on Information Systems for Crisis Response and Management (ISCRAM2010)*, Seatlle, USA.
- Bharosa, N. & Janssen., M. (2010). Extracting principles for information management adaptability during crisis response: A dynamic capability view. *Proceedings of the [43th] Annual Hawaii International Conference on System Sciences, Hawaii.*
- Bharosa, N., Lee, Y. and Janssen, M. (2010). Challenges and obstacles in information sharing and coordination during multi-agency disaster response: Propositions from field exercises. *Information Systems Frontiers,* 12(1), pp 1-7.
- Bajnath, S., Janssen, M., Bharosa, N., Both, C., Klievink, B., Overbeek, S. & van Veenstra, A.-F. (2010) Service Delivery Principles: Deriving Principles Using a Role-Playing Game. In *Proceedings of the 10th European Conference on e-Government (ECEG)*,University of Limerick, Ireland.
- Janssen, M., Lee, J., Bharosa, N. and Cresswell, A. (2010). Introduction to special issue advances in inter-organizational disaster management, *Information Systems Frontiers* 12(1), pp 49-65.

**2009**

- Bharosa, N. and Janssen, M. (2009). Reconsidering information management roles and capabilities in disaster response decision-making units. In *Proceedings of the 6th International Conference on Information Systems for Crisis Response and Management (ISCRAM2009)* Gothenburg, Sweden. Received the Best Paper Award.
- Bharosa, N., Lee, J., Janssen, M. and Rao, H. R. (2009). A case study of information flows in multi-agency emergency response exercises. In *Proceedings of the10th annual International Conference on Digital Government Research*, ACM digital library's ACM International Conference Proceedings Series, Puebla, Mexico. Nominated for the Best Paper Award.
- Bharosa, N., Van Zanten, B., Zuurmond, A. & Appelman, J. (2009). Identifying and confirming infor-mation and system quality requirements for multi-agency disaster management. In *Proceedings of the 6th International Conference on Information Systems for Crisis Response and Management* (ISCRAM2009).
- Gonzalez, R. & Bharosa, N. (2009). A framework linking information quality dimensions and coordination challenges during interagency crisis response. In *Proceedings of the [42th] Annual Hawaii International Conference on System Sciences, Hawaii.*
- Bharosa, N., van Zanten, B, Janssen, M., & Groenleer, M. (2009). Tranforming crisis management agencies to network centric organizations. *Lecture Notes on Computer Science* 5693, pp. 65–75, 2009. Springer-Verlag Berlin Heidelberg.
- Bharosa, N., (2009). (Re)-Designing information systems for disaster response: principles for assuring information quality for relief workers. In *Proceedings of the 5th Risk and Design Symposium*, Delft, The Netherlands.

**2008**

- Bharosa, N., Feenstra, R., Gortmaker, J., Klievink, A. & Janssen, M. (2008). Rethinking service-oriented government: Is it really about services? In *Let a thousand flowers bloom* (Bouwman, H. and Bons, R. and Hoogeweegen, M. and Janssen, M. and Pronk, H., Eds), pp 237-254, IOS Press, Amsterdam.
- Bharosa, N. & Janssen, M. (2008). Adaptive information orchestration: Architectural principles improving information quality. In *Proceedings of the 5th International Conference on Information Systems for Crisis Response and Management* ISCRAM2008 (Fiedrich, F. and Van De Walle, B., Eds), pp 556-565, Washington, DC.

**2007**

- Bharosa, N., Janssen, M. & Wagenaar, R. (2007). Enterprise architecture evaluation. *In Proceedings of the 2007 IRMA International Conference* (Khosrow-Pour, M., Ed), pp 834-838, Idea Group Inc., Vancouver, CA.

- Bharosa, N., Appelman, J. & De Bruijn, P. (2007). Integrating technology in crisis response using an information manager: First lessons learned from field exercises in the port of Rotterdam. In *Proceedings of 4th International Conference on Information Systems for Crisis Response and Management* (ISCRAM2007), (Van De Walle, B. and Burghardt, P. and Nieuwenhuis, K., Eds), pp 63-70, Delft.
- Bharosa, N. & Janssen, M. (2007) Informatie-orkestratie voor crisismanagement. *Informatie*, pp 56-60.

# Curriculum Vitae

Nitesh Bharosa was born in Paramaribo, Suriname on the 1st of March, 1983. After finishing the secondary school in Paramaribo, he moved to the Netherlands in 2001 to start with the Systems Engineering, Policy Analysis and Management program at the Delft University of Technology. In this period he was active in several communities and boards including the faculty student board and the inter-faculty educational board. In 2005 he received the ECHO Award for his personal and academic achievements. Since then he served as an ambassador for the ECHO foundation (expertise center for diversity and foreign talent), dedicated to empowering migrant talent in the Netherlands. After completing his master thesis in 2006 he started with a PhD research at the Faculty of Technology, Policy and Management. His research interests include information quality, coordination and orchestration, particularly in complex and heterogeneous networks such as public safety. During his research, he has supervised over fourteen students in obtaining their degree. Nitesh has served as session chair during multiple international conferences including ISCRAM and HICSS and has acted as co-editor for the Information Systems Frontiers Journal. His research has been published in several journals and conferences including Decision Support Systems, Information Systems Frontiers and the Journal of Cognition, Technology and Work. During the ISCRAM 2008 conference in Goteborg (Sweden) he received the Best Paper Award for his work on Information orchestration in public safety networks. His work on designing dashboards for disaster preparation was also nominated for the Outstanding Paper Award in the category "the most promising practical concept" during the 2010 EGOV conference. As a research associate, Nitesh continues to do research on National Single Windows and Standard Business Reporting at the Delft University of Technology.

During daily operations, relief agencies such as police, fire brigade and medical services manage information in accordance with their respective processes and organization structure. When disaster strikes, the ad-hoc combinations of such hierarchy based information systems fail to assure high information quality (IQ) and system quality (SQ) for relief workers. Disaster such as 9/11, Katrina and the Polderbaan-crash have taught us that poor IQ and SQ significantly hamper disaster response efforts and can be lethal for relief workers and citizens. Drawing on empirical data (field studies) and pathways in 'state of the art' theories, this dissertation presents ten design principles for assuring IQ and SQ in public safety networks. These principles are the cornerstones of a design theory coined as 'Netcentric Information Orchestration' and are meant to guide information system architects, practitioners, software vendors and policy makers in the (re)design of information systems for disaster response. We evaluated the design principles on their technical feasibility (using prototyping) and on their ability to assure IQ and SQ for relief workers (using quasi-experimental gaming-simulation). Findings indicate that the proposed design principles assure higher levels for most IQ and SQ dimensions.

Nitesh Bharosa works as a researcher at the Delft University of Technology. For more information regarding his academic activities and publications, please visit: www.bharosa.nl