Adaptive Information Orchestration: Architectural Principles Improving Information Quality

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ABSTRACT

Effective responsiveness to disasters requires the management of information in a network of autonomous response agencies. Yet, the information quality is often insufficient. Information is scattered throughout the network and needs to be collected from heterogeneous information sources. As such, adaptive information orchestration is the key to effective response. The aim of this paper is to develop a prescriptive, conceptual architecture guided by architectural principles for orchestration aimed at improving information quality. Information orchestration refers to an information architecture in which multiple orchestrators match information supply according to the information demand in order to assure a high information quality for relief workers. A primarily element is that information needs to be 'enriched' before it is provided to relief workers and necessary resources (human, information and technology) should be available to accomplish this. This should ensure that the right information will be delivered to the right persons at the right moment. Future research is aimed at detailing the concept of information orchestration.

Keywords: orchestration, adaptivity, information quality, Rotterdam, architecture

INTRODUCTION

Many previous contributions have underlined that for effective disaster management, access to the right information on the right level of detail at the right time is essential for making the right decisions (e.g., Dawes, Cresswel, & Cahan, 2004; Horan & Schooley, 2007). In each phase of the disaster management cycle that includes: mitigation, preparedness, response, and recovery, critical decisions must be made that require getting the right information to the right people at the right time (Board on Natural Disasters, 1999). When considering the requirements of 'the right information on the right level of detail at the right time" we can relate such requirements to information quality dimensions, respectively correctness, accuracy and timeliness. The concept of information quality (IQ) has been specified in previous research (e.g., Miller, 1996; Strong, Lee, & Wang, 1997). However, contributions on IQ in the domain of interagency disaster management are still very scare (e.g., Fisher & Kingma, 2001). Especially discussions on how to improve IQ for interagency disaster response are lacking in literature.

Establishing high IQ during interagency disaster management is a challenging task given the nature of a disaster. Interagency disaster management is considered to be a very complex process (Bigley & Roberts, 2001), requiring many, and often unprecedented, interactions between multiple relief agencies and incompatible information technology. Moreover, the environment of disaster management is dynamic (Comfort, Sungu, Johnson, & Dunn, 2001) implying a high level of uncertainty (Argote, 1982) and information need unpredictability (Longstaff, 2005). Under such conditions, decisions should be made under time-pressure. In other words, as complexity, dynamics and uncertainty are dominant contingency factors; low IQ is a problem for interagency disaster management. This is further complicated, as information might not be actual anymore or simply wrong.

Against this backdrop, the aim of this paper is to develop a prescriptive, conceptual architecture for orchestration aimed at improving IQ. Accordingly, the main question addressed in his paper is formulated as: *what architectural principles are necessary to improve the information quality during interagency disaster management?* The main premise underlying this research is that by improving the adaptivity of the information architecture IQ can be ensured. Hence adaptivity is considered to be a prerequisite for improving IQ. This paper proceeds with a brief description of the research approach. Next, this paper discusses some findings from literature leading to requirements on orchestration. Then, a case study is discussed. Based on literature and the case study, the orchestration architecture is presented. Finally conclusion and recommendations for future research are drawn.

RESEARCH APPROACH

For the purpose of developing a conceptual architecture for orchestration aimed at improving IQ, we use two research instruments: literature analysis and a case study. Literature analysis is necessary for the description of IQ problems and requirements for information orchestration. The second research instrument is the case study approach. Considering the lack of experimental control inherent in the domain of disaster management, an exploratory, case study-based approach is necessary. According to Yin (2003), case study research is most appropriate in scenarios where the research is exploratory in nature and focuses on contemporary events that occur beyond control of the investigator. Because we want to collect data first hand, studying real disasters was not a viable option. Hence we chose to study disaster management exercises that mimic real disasters as much as possible. The case study is used to identify hurdles for IQ and elements for an orchestration architecture. The research has an explorative nature as limited theory is available in this field. The following scheme illustrates the research approach and the structure of this paper.

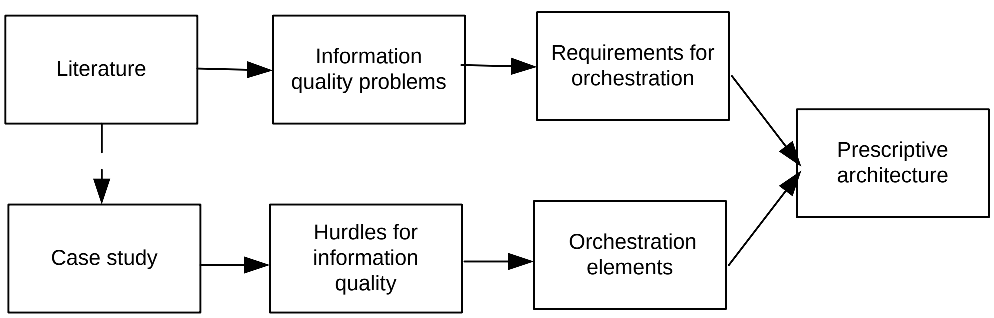


Figure 1 Research approach

INFORMATION QUALITY: PROBLEMS IDENTIFIED IN LITERATURE

IQ is multidimensional concept, capturing a wide range of variables such as accuracy, timeliness, completeness, consistency, relevancy and fitness for use (Wang & Strong, 1996). Miller (1996) adds format, compatibility, security and appropriate amount of data as important variables for measuring the IQ. Fisher and Kingma (2001) argue that the quality of information is critical for effective disaster response. Their work suggest that because decision-making is based on available information, if the process of integrating the information is flawed, or its communication (sharing) is flawed, then decisions based on that information are more likely to be flawed. When analyzing problems related to information put forward in evaluation reports of interagency disaster management, we find that these problems relate to IQ dimension. The scope of the literature analysis was limited to the IEEE, ACM and Blackwell libraries that were consulted in 2007. The following table lists some frequently discussed IQ problems in literature.

IQ Dimension	IQ problems identified in literature
Accuracy	Information about technical conditions may be ambiguous and unreliable (Kontogiannis, 1996). Furthermore, a significant lack of information, then turns into large amounts of imprecise information (Manoj & Hubenko, 2007). Such wrong or incorrect data leads to an insufficient distribution of resources (Fisher & Kingma, 2001).
Timeliness	Emergency situations changes time by time so it is very important to know the order of

	events and their cause-effect relations (Atoji, Koiso, Nakatani, & Nishida, 2004).
Relevance	Certain events when viewed in isolation may appear irrelevant or benign in terms of the emergency, but when analyzed collectively may identify a potential threat (Adam et al., 2007).
Quantity	A great deal of information occurs in a short period of time (Atoji et al., 2004), resulting typically in too much information to process (Jenvald, Morin, & Kincaid, 2001) and straining the capacity of the emergency management and communication systems (Manoj & Hubenko, 2007).
Completeness	There are potential response delays influenced by availability of information about the incident, correctness of information about the incident, completeness of information, and quality of information dispatched (Chen, Sharman, & Upadhyaya, 2005).
Format	To enable information sharing, document type definitions have to be in a well-defined format that is easily accessible across a heterogeneous crisis response network. While the format of data is arbitrary, the format of data definitions needs to be rigorously defined (Jenvald et al., 2001).
Security	Security is a common concern 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). Sharing and dissemination of information during an emergency is challenged by trust on the source and security issues (Manoj & Hubenko, 2007).
Consistency	If several information systems suggest different location coordinates, this inconsistency delays decision making (Fisher & Kingma, 2001).

Table 1: Some IQ related problems pointed out in literature

Despite the many attempts to conceptualize the notion of IQ, there are very few contributions on how to improve the IQ, especially in the domain of interagency disaster management (e.g., Fisher & Kingma, 2001). While there is much literature suggesting that these criteria have not been satisfied (e.g., Dawes et al., 2004), there are only a few that discuss why they have not been satisfied or what the hurdles are (e.g., Fisher & Kingma, 2001). The next section describes some hurdles in practice.

CASE STUDY: DISASTER MANAGEMENT AT THE PORT OF ROTTERDAM

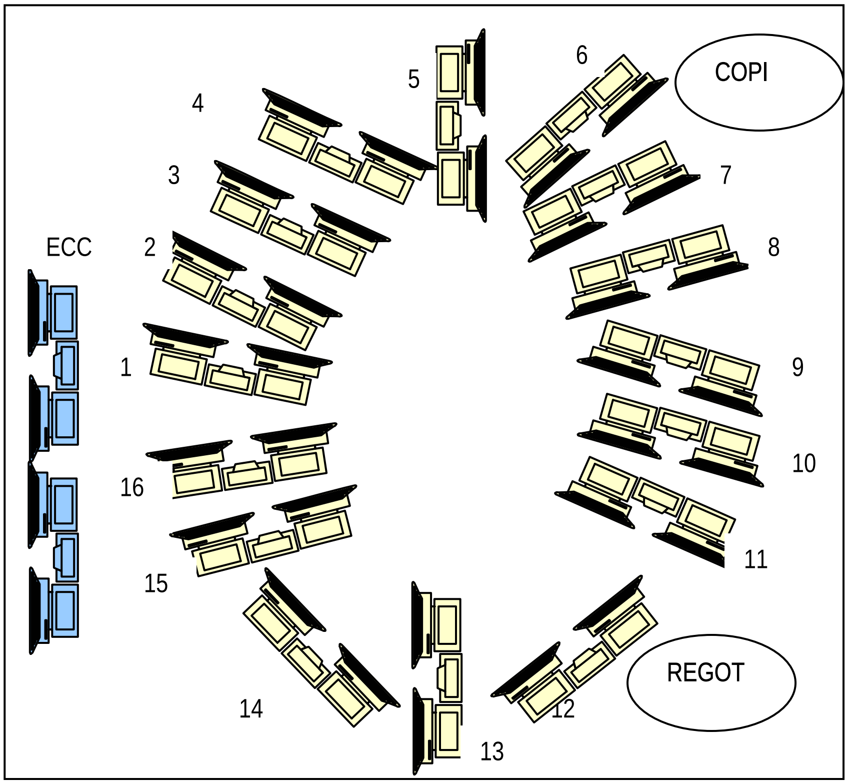
The aim of the case study was to identify hurdles hampering high IQ and elements necessary for orchestrating information. Amongst the world's largest seaports, the Port of Rotterdam (PoR) is about 10500 ha housing an estimated 1600 companies. To ensure prepared of local disaster management organizations, the Safety Region Rotterdam-Rijnmond stimulates recurrent disaster management exercises in the port area for various relief agencies to exercise together on various levels. Previously, Bharosa et al (2007) have already published results of case studies in the POR. One of the follow up exercises that were organized in 2007 was the Information Technology (IT) exercises. These exercises were organized indoor for three days, containing three rounds per day. The objective of this type of exercise is formulated as: "Introducing advanced information systems to relief workers, including commanders of the relief organization that participate on the decision making levels of disaster response". During these exercises a Voice over IP system was introduced to relief workers from multiple agencies, including the Police, Fire department, Medical Services and Harbor Police. This is different from reality where each relief agency has there own preferred communication systems which are not compatible. The participants were real agents representing each agency on different levels of crisis management, including the operational level (field units), the tactical level (head officers) and the strategic level (regional officials and Army leader). The following table provides an overview of the conducted case study.

Focus	Introducing relief workers with information and communication technology.
Management Levels	Operational level (first responders), tactical level (COPI), strategic level (ROT) and Emergency Control Centre
Participating Agencies	Police Department, Fire Department, Medical Services, DHMR (Division Harbor Master Rotterdam), CVD (Center for public service)

Setting	Computer aided simulation, Indoor
Schedule	June 5th, 19th and 26th 2007
ICT Tools	ICIS, CeDRIC, GROOVE, WAVE

Table 2: Basic characteristics of the observed exercise

The entire exercise is conducted in one room (without any sub rooms/compartments). In the center of the room a beamer/screen was set up, allowing for collective explanation and evaluation of the exercise. The following figure provides an illustration.



Nr.	Emergency service
1	Leader REGOT (Regional Operational Team)
2	Public spokesperson COPI (Commando Place Incident Team)
3	Information Manager in COPI
4	Chemical advisor in COPI
5	Officer Division Harbor Master Rotterdam in COPI
6	CVD (Center for public service)
7	Chief Officer Police Department
8	Chief Officer Fire Department (Leader COPI)
9	Chief Officer Ambulance Services
10	Public spokesperson REGOT
11	Information Manager REGOT
12	Chemical Advisor in REGOT
13	Field Officer Chemical Experts
14	Field Officer Police Department
15	Field Officer Ambulance Services
16	Field Officer Fire Department

Figure 2: Schematic overview of the exercises

In total 16 workbenches circled the center of the room. The numbers at each workplace represent a specific agency participating in the exercise. Each workplace represented an actor and contained two PC's and a printer. Each actor was represented by one or two persons. The scenarios that were followed during the two rounds of exercises were basically the same, with the exception of three elements: the location, the magnitude and the information structure. The main ingredient of the scenario was the collision of two ships, a containership and a passenger ship. On the container ship an explosion occurs. Because of the potentially hazardous chemical material on the container ship the containership can be very harmful, not only for the passenger ship, but also for the neighboring ships and factories in the area.

Case study findings: hurdles

During the observations in the Port we looked for more hurdles next to interoperability that hamper the IQ for relief workers. Disaster response requires multiple agencies to work together and information needs change rapidly as the disaster evolves. For instance, providing relief workers with consistent information on the severity of a fire is difficult as the severity keeps changing and the different relief organizations have different measures for the severity. Moreover, each organization has its own information systems and information sources that usually do not inter-operate. In the current information architecture there are multiple implicit (informal) information managers on multiple levels. For instance the COPI and ReGOT decision making teams each have an information manager who is equipped with a laptop running various ICT application. On the other hand the control room also functions as an information manager, feeding all levels of response with information. Generally, we found that as the disaster evolves and the complexity (in terms of amount of actors and necessary interactions) increases, the IQ decreases. A number of IQ related hurdles were identified. The following table provides an overview of the findings.

Hurdle description	Impact on IQ
1. Source heterogeneity: each relief agency has their own information source in the control room. The data to be integrated and disseminated is heterogeneous, both structurally and semantically.	**Low consistency:** the members of the various agencies have different information on for instance the exact location of the incident.
2. Information is only pushed and not validated in the control room.	**Low validity:** relief workers have get information that is incorrect or outdated.
3. During decision making rounds, relief workers are not provided with real time information and make decision based on an outdated situational picture.	**Low timeliness:** decision makers do not get up to date information on the situation and make decisions based on outdated information.
4. When following the GRIP procedures, only the decision making responsibility is altered, the information responsibility as previously arranged at the control room stays the same	**Overload:** the control room has to feed more levels of decision making and has less time to collect information from the field units.

Table 3: Hurdles for IQ

The hurdles stated in the table imply that the current way information is managed is insufficient as the complexity and the dynamics of the disaster evolves. We propose a information architecture in which information orchestrators are included to ensure higher IQ. Here, we follow the definition for architecture provided by the IEEE 1471 standard (Hillard, 2000), in which architecture is defined as “the fundamental organization of a system embodied in its components, their relationships to each other and to the environment and the principles guiding its design and evolution’’. Architecture can be used as a descriptive (analysis) or a prescriptive (design) instrument (Bharosa, Janssen, & Wagenaar, 2007) . In the following section the concept of information orchestration is detailed.

ADAPTIVE INFORMATION ORCHESTRATION

Adaptive information orchestration is a key concept for getting the right information to the right responders at the right time in the right format. Research in domains such a supply chains have put forward solutions to similar problems, for instance mediators (e.g., Wiederhold & Genesereth, 1997), brokers (e.g., Van der Lee & Van Vucht, 2004) and portals (e.g., Boyson, Harrington, & Corsi, 2004). The common idea behind these solutions is to provide intermediary services, linking data resources and application programs. Because such solutions are developed for supply chains with a fixed configuration of predictable actors, their applicability in the domain of interagency disaster response is limited.

Regardless of the fact that these solutions are technology driven and do not provide a high level of adaptivity which is needed in the domain of interagency disaster response, we recognize potential concepts that can help in the development of a conceptual architecture that can improve IQ in the domain of interagency disaster management. Especially the work of (Wiederhold & Genesereth, 1997) on mediators provides insight for the development of the conceptual architecture. The basic idea behind mediation was to provide integrated information throughout a network of autonomous organizations, without the need to integrate the base data resources. We believe that this is a necessary prerequisite for any of information architecture in the domain of interagency disaster management where multiple autonomous agencies need to act together only on occasion. However, due to the complex, dynamic and unpredictable nature of disasters, integration solely is insufficient for a high IQ. We believe that some form of intelligence in mediating information is the key. Moreover, it needs to be clear who needs which type of information, when, in which format and in which level of detail. Hence we opt for an architecture in which information roles are formalized and information is orchestrated in the network of agencies.

Information orchestration can be described or prescribed using architecture. Together with other architectures such as the process architecture, the application architecture and the infrastructure architecture, the information orchestration architecture forms the blueprint for the information system across multiple agencies.

ARCHITECTURE PRINCIPLES

Our objective is to improve the IQ and system quality for relief workers by designing information orchestrators in disaster response networks. We consider such information orchestrators (e.g. the emergency control center) as a socio-technical system that can be described and prescribed using information architectures. Accordingly, any orchestrator is a constellation of multiple resources, including humans, information and information technology performing specific functions and providing different information services. Even though an orchestrator can take multiple forms depending on the situation needs, the main process the orchestrator supports is the adaptive matching of information supply and demand. Accordingly, we define adaptivity as the socio-technical system's capacity to dynamically match information supply according to the demand under changing circumstances. Because the information demand sometimes surpasses the information supply during the first hour of a disaster, we opt for the availability of specific value added services (e.g. information libraries, simulation and validation) for ensuring adaptivity. Viewing adaptivity as an essential architecture prerequisite, we expect that an enhanced adaptivity will better enable information systems to continuously match the dynamic information demand and supply in a network of responding agencies, ultimately fostering a high IQ for relief workers. In the context of interagency disaster management, this means that relief workers should be provided with, or according to the Network Centric Concept (Alberts, Garstka, & Stein, 2002) should themselves able to access information that is at least correct, consistent, accurate, complete and valid.

Requirements for information orchestration

An architecture needs to be based on a set of guiding principles (Hillard, 2000). There can be found various definitions of principles. Principles are 'beliefs' upon the enterprise is created and the basis of decisions (Richardson, Jackson & Dickson, 1990). Principles are most stable and have far reaching consequences. Multiple architecture frameworks can be found in literature, such as the GERAM, DODAF and TOGAF. The latter defines principles as general rules and guidelines, intended to be enduring and seldom amended, that inform and support the way in which an organization sets about fulfilling its mission (Perks & Beveridge, 2002). Principles can be found in the business process reengineering movement (Hammer, 1990) and the enterprise information architecture (Richardson, Jackson, & Dickson, 1990) paradigm. The following table lists seven principles for an information orchestration architecture dealing with the hurdles found in the case study.

Principle	Possible application	What problem does it solve?
1. Define library containing information based on the experience from previous disasters together with some field experts.	A list with potential information sources with data on a wide range of disaster types and guidelines for the collection, sharing and posting of information.	Re-inventing the wheel and uncertainty on how to manage with information. Dealing with hurdle 1.
2. Find 'in all situations necessary' information at the start of each disaster and post these at the information buffers.	Standard information that is necessary during all types of disaster can be collected immediately and consistently at information buffers.	Information loss while decision makers are meeting and extra delay of finding basic information. Dealing with hurdle 1.
3. Evaluate and validate the correctness of information.	Comparison of information from different sources based on multiple expert defined criteria for correctness.	Confusion and unnecessary discussions on the correctness of information. Solving hurdle 2.
4. Reserve human capacity in crisis management teams for the collection, evaluation and distribution	Next to the reservation of capacity for relief work and decision making, extra capacity could be reserved for people who check and double check	Reduction of chances that decisions are made based on incorrect or outdated information. Dealing with

of information.	information.	hurdle 3.
5. As the crisis evolves, anticipate the need for information and search the necessary data in advance.	The use of crisis simulation models or future scenario based situation analysis.	Anticipation of the information need can cut down the search time for information during decision making. Dealing with hurdle 3.
6. Selectively push information to specific relief workers.	Prioritization of information based on task and only high priority information will be send to specific relief workers.	Selectivity in which information is pushed to relief workers will reduce information overload. Dealing with hurdle 3.
7. Make the source of information responsible for updating the information (Hammer, 1990).	Hospitals update their own real time capacity and other relief agencies are able to access the up to date capacity.	Reduction of chances that outdated information is used to allocate resources. Dealing with hurdle 3 and 4.

Table 4: Architecture Principles

PRESCRIPTIVE ARCHITECTURE

The key concept of orchestration is that the available data sources (supply) are matched to the needed information by relief workers (demand). Previous work and our case study indicate that several principles are of essential importance for enhancing adaptivity and should be part of an orchestration architecture. The table is not exhaustive and other principles still need to be explored.

The first principle in the table suggests that information orchestration should be initiated prior to the moment that a disaster actually occurs. 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 relevant information might be collected more rapidly. In addition, this library should contain experiences from previous disasters (principle 1). At the start of the disaster, information that might be necessary needs to be collected (principle 2) and continuously updated (principle 5) by the source agency itself. All information is stored immediately to avoid loss in case of failure. Next, information should be correct and validated (principle 3). As information coming from different domains is necessary, having only one single information manager has its shortcomings (Bharosa, Appelman et al., 2007). As such, experts having experience in these domains should be part of the orchestration architecture (principle 4). Moreover any orchestration architecture should contain human and automatic information processing activities. Humans need often to be involved during all the information processing phases, as we are dealing with unstructured information and decisions should be made by the accountable (group of) persons. The main information processing phases are receiving, storing, validating, enriching (by searching and matching information) and distributing information. Content and context-dependent information might be selectively pushed forward to relief workers and decisions makers (principle 6). For this purpose, relief workers should retrieve and enter data and the device used could have sensors to capture the location and other information. Finally, apart from information processing, the orchestrator needs to store several databases. Finally, information related responsibility should be clear and the information sources should be responsible for updating (principle 7). All layers can be translated into activities executable by both human and machine. These principles result in our initial conceptual architecture for information orchestration. The orchestrator is divided into three layers; decision-making, information processing and information storing.

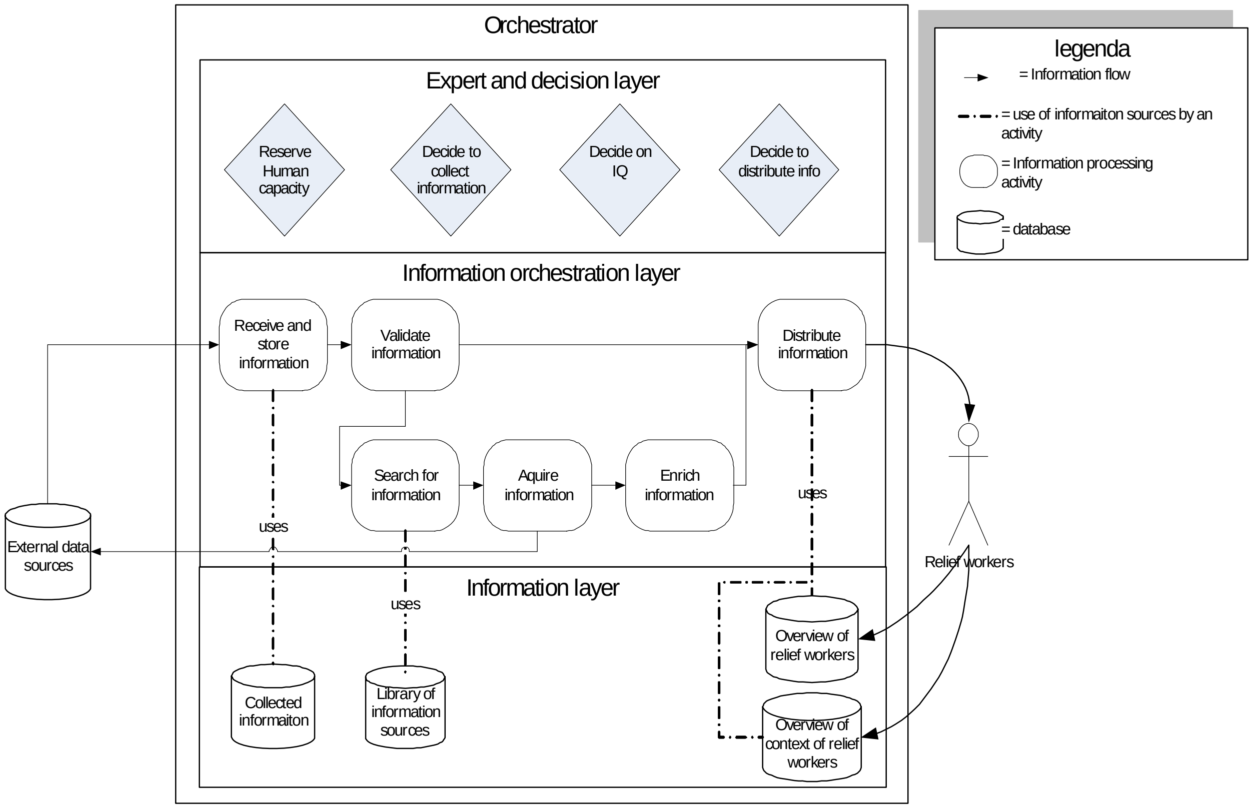


Figure 3 Prescriptive architecture of orchestrator (conceptual level)

The conceptual architecture is generic and we expect that it can be used for the (re)design of information architectures other than for the Port of Rotterdam. Central in the proposed architecture is the information orchestration layer. The main purpose of information orchestration layer is to enhance the adaptivity of the information architecture by acquiring information and matching the supply and demand for information. Adaptivity on multiple architecture layers is necessary in order to cope with the hurdles identified in this research. This means that if we want to improve the IQ for relief workers by enhancing the architecture adaptivity, we need to implement design principles across each of the architecture layers. These principles can be used as a guidance to develop information orchestrating systems. In future research they need to be specified and validated, and if necessary extended, and ultimately translated into system requirements. We believe that the main design challenge for information orchestration lies in the allocation of new responsibilities in a network of autonomous agencies. New types of responsibilities, functionality and processes are necessary to decide how actors collect, store, enrich and disseminate information.

CONCLUSION

This paper presents the preliminary findings of an ongoing research into adaptive information orchestration for improving information quality (IQ) during interagency disaster management. Central in this paper is the need for information orchestration to enhance the adaptivity of the information architecture. Because the current information architectures are designed to support the mono-actor information needs during routine (non-crisis) operations, these information architectures are yet not able to cope with changing and unpredictable information demands during multi-actor disaster response. We found that there are several hurdles that need to be overcome if IQ is to be improved. Our first findings indicate that enhancing the adaptivity of information architectures by using information orchestrators that match information supply according to demand will improve the IQ for relief workers. Information orchestration refers to an information architecture in which multiple orchestrators adaptively match information demand and supply in order to assure a high IQ for relief workers. The prescriptive architecture for adaptive information orchestration presented in this paper captures the most important architecture elements, including layers and principles guiding the architecture design and evolution. This prescriptive architecture might be of help for information architects, despite the fact that it is only on a conceptual level. In future research we intend to investigate how such an adaptive information orchestrator can be specified in more detail, and test it using interactive gaming to specify how these elements will enhance the architecture's ability to adapt to changing circumstances and ultimately improve IQ for relief workers.

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