Designing Information Marketplaces for Disaster Management

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Abstract. Disaster management always needs to strike a balance between preparedness and flexibility. The challenges of industrial crisis information management are manifold, out of which we address the question: How to create the best possible information sharing solution for a given environment and crisis situation? This ongoing design science research has identified essential components to be assembled in an 'information sharing kit', including description of informational needs, data model, categorization of ICT components, and guidelines for kit usage. All of these can and should be further developed towards a localized crisis information sharing kit, on the basis of which specific information sharing solutions can be set up in order to create information marketplaces for response and recovery whenever crises occur. Insights from this research are expected to inform disaster preparation in practice, especially in ICT empowered community settings such as smart cities, and to identify more clearly the (research) needs for standardization in disaster-related information management and integration.

Keywords: disaster management, information sharing, information marketplace, localized information sharing kit, design science research

1 Introduction

Industrial disasters often cause loss of human life and damage to the environment. The disastrous impacts even increase when information sharing during crisis management does not succeed to orient and empower the stakeholders involved towards appropriate action. While the advancements in information and communication technology (ICT) entail new opportunities for information sharing, disaster management is challenged by the growing availability of potential relevant information sources as well as by the complexity of managing the collection, processing and sharing of data through multiple channels with those who have urgent, but mostly specific informational needs.

For adequate reaction, disaster management always needs to strike a balance between preparedness and flexibility. But how to reach this balance on the level of computer-supported information sharing is still unclear. Therefore our research question is: How can the stakeholders in charge create a suitable ICT infrastructure for information sharing during specific crisis response and recovery? We propose using an information marketplace as guidance for implementation information sharing solutions for disaster management. Essential components can be assembled into a localized ‘information sharing kit’ during disaster preparation, and based on such readiness a specific information marketplace can be set up ad hoc whenever a crisis occurs.

The next section briefly characterizes the unique attributes of industrial disasters, crises management and related challenges of information sharing. Section 3 conceptualizes the idea of information marketplaces for disaster management as an open ensemble of accessible structured data supplies and explicit use-case based informational demands to be matched through dedicated algorithms. Section 4 reports about the ongoing design science research to provide a proof-of-concept for this approach. The conclusion signifies the contribution to the field and points to future research.

2 Informational challenges in industrial disaster management

A crisis is an unfamiliar event that has a low probability of occurring while causing high-risk consequences if not managed properly. Industrial crises are classified as accidental crises, when caused by technical errors that are equipment related, or as intentional crises, when the cause is human error from poor performance. These accidents are stem from factories such as nuclear power stations, energy factories, toxic material using factories or normal factories that could catch fire. Situated mostly in urban areas, industrial crises are especially difficult to manage because of the number and diversity of actors involved, the variety (and often volatility) of needed data and information to be processed and communicated, and the complexity and vulnerability of the ICT infrastructure in place.

An industrial crisis involves internal stakeholders (e.g. employees and managers) and external stakeholders (e.g. media, civilians) [22] as well as disaster management organizations (DMOs), including public safety personnel, healthcare, transportation, the government, and sometimes even the army [4]. These stakeholders are expected to make sense of the situation while there is shortage of information as well as short-time for response [13].

The negative impact of industrial crises often increases due to information management problems among these stakeholders during the management of the crisis. The process of managing an industrial crisis is divided into different phases, each with different information management challenges. Most authors agree to the basic classification into pre-crisis, crisis and post-crisis phases, albeit with variations regarding pre-crisis activities. Here we adopt the approach of Hilliard et al. [9] to differentiate only two pre-crisis phases, preparedness and mitigation, followed by the remaining phases response (during the crisis) and recovery (post-crisis).

During pre-crisis phases data is collected to evaluate the organization’s performance, i.e. to assess the preparedness for a crisis, including role awareness, prerequisites for crisis response, and actions for crisis prevention [25]. Another stream of data sourcing regarding previous crisis triggers, abnormal factory performance measurements and environmental data is used to detect anomalies [2], predict crises [18], generate vulnerability maps, identify crisis management requirements [1], and assess risks and vulnerabilities [8, 3].

All the stakeholders involved in the crisis should be kept up-to-date with each other's performance evaluation and early warning signals in order to ensure preparation alignment and to avoid role duplication, missing requirements or preparing plans that do not match the crisis requirements [25]. However, a lack of common ground in terms of terminology and means of communication [19] as well as each entity focusing on its own needs may hinder this information sharing and coordination [4].

During crisis response the events are monitored and immediate response is offered accordingly including rescue, evacuation, issuing warnings, and updating the public with ongoing events [7, 1]. As poor response might lead to an even more severe disaster than the crisis itself, the right information must reach the right person at the right time to carry out timely response. However, the information sharing in this phase is challenged by the low cohesiveness of the crisis management teams; e.g. due to role duplication across different organizations [25], the shortage of time available for the teams that often had not worked together before to nurture ties and build trust in each other, and/or the lack of common ground between these teams where each team has its own processes to handle a crisis, its own terminologies used during communication, and its own ICT support. Accordingly, it is difficult to access and filter the right information to be shared and to identify appropriate channels for information sharing. Furthermore, crisis information overload, along with the limited availability of communication channels, often lead to bottlenecks in information flow, causing communication failure and delays in data collection and processing; possible implications include inefficient filtering of information and the information getting outdated due to the continuous change in circumstances [16, 7].

Any delay in data collection would lead to going blind into the interpretation phase [22], resulting into either incomplete or conflicting interpretation of the crisis events. For interpretation, the inconsistent/irrelevant data is removed and the remaining data is analyzed to reach an understanding about the crisis [25, 7]. The information sharing itself then is often impaired by reduction of available communication channels, emergence of new uncontrolled communication channels (e.g. social media), poor communication filters to prioritize information and to distinguish between crucial and safe-to-ignore information [16, 7, 19], and low vertical and horizontal interaction inside and across DMOs [11].

Day et al. [6] summarized the challenges in data collection as inadequate stream of information, data inaccessibility, data inconsistency, low information priority, source identification difficulty, storage media alignment, and unreliability. These challenges include inadequate data collection methods, time pressure and limited resources for decision-making, as well as conflicting crisis interpretation and data processing [13]. Scholl et al. [24] found that hazard-related planning is not sufficient to support systematic information collection and sharing and that standardized information sharing procedures and information integration practices are lacking; from the technical perspective they call for more research on common information architecture and information system platforms. Challenges are also faced in designing audiencespecific messages [7], and often no attention given to sharing crisis information with citizens affected by the crisis [16].

In principle, an abundance of ICT is available to handle the information management and communication during an industrial crisis. For example, DMOs often use Disaster Management Decision Support Systems to collect and analyze data for supporting crisis response [1]. However, a crisis experiment implemented by Bharosa et al. [4] showed that even though 72% of participants see ICT as valuable, 74.7% are not satisfied with existing ICT solutions.

With the advancements in public infrastructure, especially in smart cities, and an ever increasing range of data from IoT-related sensors and smart cards [12] new options for improving data sourcing and processing in various phases of disaster management need to be explored. Opportunities for information sharing according to the users' needs nowadays include more dedicated channels and platforms such as smart phones, internet, social networks, online-mapping and cloud computing [20], and the public infrastructure should be linked with applications, social learning and governance to build knowledge bases for citizens and enable collaboration [10, 15].

Thus, the public infrastructure offers an opportunity to overcome the information management challenges in crisis management by utilizing its technological solutions during response and recovery: sharing the crisis details, and the response and precautions to be taken to the affected citizens; sharing up-to-date information between the DMOs needed for crisis management; ICT solutions offering a balance between flexibility and preparedness in the communication during crisis. Scholl and Patin [24] emphasize that actionable information requires "resilient information infrastructures" that should be "redundant and resourceful", i.e. combining ICT with social, organizational, and knowledge assets.

3 Information marketplaces for disaster management

Given the array of potentially valuable data sources and the challenge to manage comprehensive information sharing in very short time, new option for automating the information sharing have to be explored. Numerous research papers have pointed out the challenges, but solutions have been rarely proposed. Accordingly, our research question is: How to design a suitable ICT infrastructure for information sharing during crisis response and recovery? The vision is that stakeholders in charge may implement a situated information marketplace based on a kit of publicly available and/or prefabricated components.

Information marketplaces have been mainly studied from the economic perspective and also have been used to conceptualize the 'smart city' [5]. The core idea is that 'raw data' is transformed and/or perceived as a valuable information product to be consumed by those in need for this information (and who are willing to pay a premium for it). In disaster management, multiple stakeholders are in need of comprehensive and diverse information, most of which is predictable in principle, but not specifically. The types of stakeholders and their communications channels also can be largely foreseen (depending on the type of crisis) but again not the specific persons or groups. However, the preparation of disaster management includes multiple scenarios of crisis analysis and response through which informational needs and available data and its accessibility can be identified in advance, at least in principle, allowing for preparing the information sharing based on a standardization presenting potentially relevant data as an informational product to be consumed. If we aim also for automating the match between informational demands and supplies, then also the informational needs have to be described in a standardized way, i.e. through generally known attributes, to enable a matching algorithm to present relevant data to the right informational users through the available channels. To some extent Saleem et al. [21] had prototyped this idea in terms of a "Business Continuity Information Network"; for this purpose they had identified (a) the necessary informational components as disaster management dataspace, disaster recovery resources identification, situation awareness, dynamic contact management, and intelligent decision support, as well as (b) algorithms for retrieving and presenting relevant information to users.

In our approach, we take the idea of an information marketplace to the next level of abstraction so that the elements of the information flow realization become visible and each of these elements can be supported by selected kit components. Hence, the information marketplace is conceptualized as an open ensemble of accessible structured data supplies and explicit use-case based informational demands, both matched through algorithms that may follow different types of market regulations (see fig. 1).

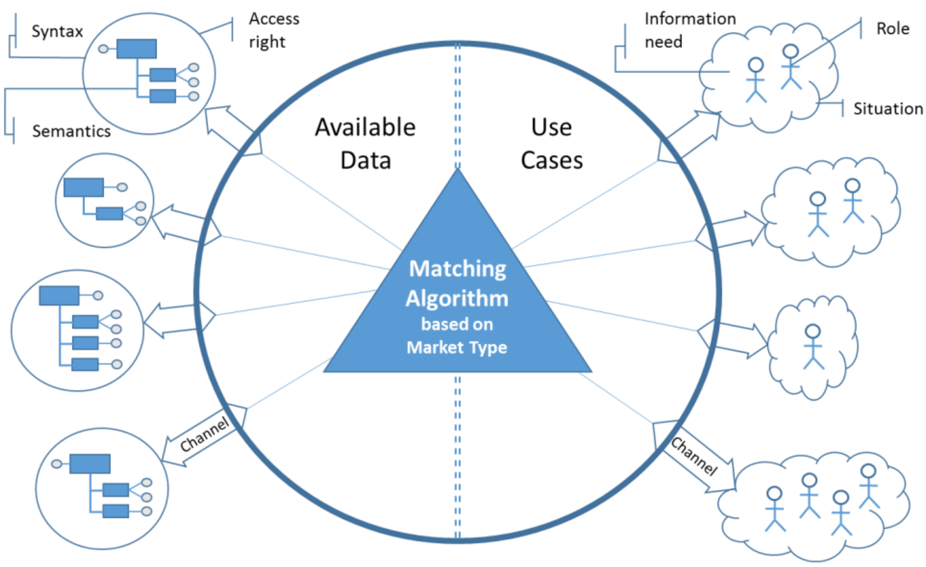

Fig. 1. Conceptualizing an information marketplace for disaster management

While every community may prepare for such market in its own fashion, the mechanism of any electronic marketplace requires similar components and preparations:

1. *Available data:* Turning data into useful information can only happen when

- information users know about its existence (presentation to users is to be organized by the matching)
- users have the right to access the data
- users are able to manage the communication channel for accessing the data
- the data can be processed based on the known syntax (e.g. XML, streaming data, VoIP)
- the meaning of the data (semantics) is known and can be related to the users' needs

How to define the semantics can follow different paths. Existing ontologies should be reused as much as possible, and given communities can identify their own categories of meaning. For example, Pan et al. [16] have identified and described four types of crisis response information: personnel status, infrastructure, crisis management and notification, area access. Standardized descriptions in each of these areas could be used to describe informational needs in various use cases and to define and annotate metadata for the available datasets (see [14] for review of available ontologies). In any case, it needs a standardized description and architecture of what Scholl et al. [24] call "essential elements of information."

2. *Use cases:* Turning data into useful information happens only when users can meaningfully interpret the data for improving their action. For matching the available data with the information demand, the different cases of information use have to be described for automatic analysis:

- *Roles*: types of actors and their usual responsibilities and activities
- *Situations*: circumstances of role implementation (e.g. weather conditions, available transportation)
- *Informational needs:* type of information specified by actors involved

All of the above may not be fully described, or only through full text descriptions. The more the use case description is based on shared ontologies, the more options exist for automatically matching informational needs and supplies.

3. *Matching algorithm:* In order to manage the complexity of serving informational needs with available data, the matching should be automated. However, presenting available information to users has to balance precision and recall in terms of relevance of the information to the use case at hand. Besides, for organizational reasons the information sharing might need to be well regulated, e.g. one agency wants/must control who receives which information or seeks to apply certain filter mechanism to control for data quality (e.g. reliability) and to enable a more efficient information consumption. Hence, the market can be set up according to predefined types, each supported by dedicated matching algorithms, for example:

- *Free market:* all participants can see, access and consume all available data
- *Central Agency:* the visibility of data, all matchmaking, and all information consumption is controlled by one central agency in charge

- *Demand pull:* a given description of a use case is automatically analyzed and available data is constantly provided based on predefined rules.
- *Supply push:* whenever new data is available potential users are notified; users may define certain subscriptions (feeding filters)

The DMOs and the community at large should agree on the type(s) of market to prepare for. However, during crisis the applicable type might even change due to situated analysis of the information demand and supply.

4 Designing an information sharing kit for crisis management

This ongoing research has adopted a design science approach, which is the process of creating new and innovative artifacts to address a certain problems. It explores the opportunity of using existing ICT components to prepare a "crisis management information sharing kit" (i.e. not a ready-made solution) that can be flexibly used to set up an information market for specific crisis incidents in a given environment (e.g. a smart city). In this section we discuss the approach to and the results of the design science phases as structured by Peffers et al. [17].

Beyond literature review *problem understanding and identification* was achieved through interviews with personnel from DMOs, followed by assessing different crisis scenarios. Semi-structured interviews were conducted with the sheriff's deputy of a police station and a lieutenant-colonel in fire department located in a very large city. The interview questions asked for crisis notification (how? when?), exchange of crisis incident information in real-time with other DMOs (what information is shared and how?), information to be shared with citizens (what information and how?), problems of information sharing, informational needs related to types of industrial accident (what information from which source?). Interview results revealed marginal use of ICT for data sourcing and information sharing processes as well as a lack of clear instructions on information to be shared between DMOs and between police officers/ fire fighters and affected citizens during industrial crisis. Furthermore, available crisis documentation was used for problem confirmation and objectives identifications. Governmental and news reports have been analyzed regarding crises that occurred during the last ten years in industrial facilities facing a fire, a leak, an explosion and/or building collapse (Fukushima 2011, Kaohsiung 2014, Savar/Rana Plaza 2013, Ludwigshafen/BASF 2016, Waco/West Fertilizer 2013, Port Wentworth/Georgia Sugar Refinery 2008). In line with previous literature it was found that, even though some information sharing happened, multiple challenges still hindered timely information sharing especially among DMOs and between DMOs and citizens and that appropriate ICT solutions have usually not been in place.

The basic *design objective* is to enable key stakeholders to set up and/or adapt ICT solutions for providing the needed information during response and recovery of the industrial crisis in focus. The core objective is to design artifacts for supporting a strategic approach that identifies and creates components as far as possible during crisis preparation in order to swiftly and flexibly realize a situated ICT-powered information market when needed during crisis response and recovery.

The *artifact design* includes so far:

- Informational demands are categorized into person/organization account, situation assessment, rescue alert, relief claim, volunteer request, supply request, evacuation/routes, medical care, specific roles (e.g. fire fighters, police officers) and DMO monitoring, exemplified by 70 user stories (i.e. intended/planned activities that require specific information)
- Entity relationship diagram with several hundred entities, relationships and attributes as a possible blueprint for stakeholders to identify and model relevant data
- Categorization of typical ICT infrastructure components for channel management, including hardware, software (in particular the market place mechanics), operating system, data management and storage, telecommunication, internet platform, standards (e.g. ontologies), and even consultants or other IT services
- Guidelines to assist kit users in (a) preparing their localized information sharing kit (including analysis of past/expected local crises, identifying users and their informational needs, preparing access to available data, developing information sharing mechanisms and test solutions) as well as (b) transforming the localized kit (including crisis analysis, specifying users' information needs and communication channels, choosing and combining existing components, making adjustments) into an actual information sharing solutions for crisis management (e.g. mobile apps, information portals, multi-layered maps, news feeds, billboards; see figure 2)

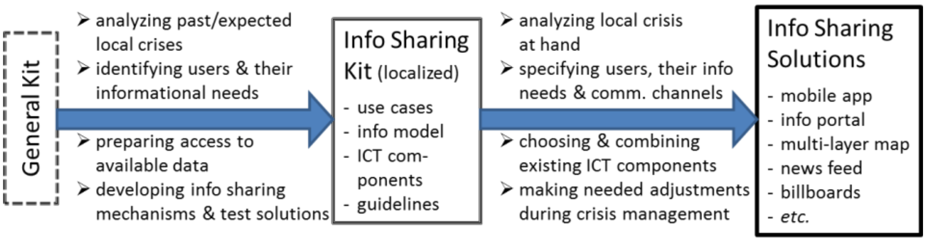

Fig. 2. Transformation of the information sharing kit into ready-to-use solutions

The *artifact demonstration* aims to involve numerous and diverse members of DMOs trying to use the kit components during a simulation of crisis preparation and management. The *artifact evaluation* then focuses on the usability of the kit and its effectiveness in terms of creating suitable localized 'markets' for crisis-related information sharing. Data collection for evaluation includes observation during simulation as well interviews of participants after simulation.

5 Conclusion

Previous research has found that information sharing during disaster management is not adequately supported by ICT solutions. As standardized data management and information integration procedures and practices are still in its infancy, disaster management has difficulties in striking a balance between preparedness and flexibility. In order to support responsible stakeholders we propose using an information marketplace as guidance for the implementation of specific information sharing solutions for disaster management. The ongoing design science research has identified essential components to be assembled in an 'information sharing kit', including description and categorization of informational needs, data model, categorization of ICT components, and guidelines for kit usage. These can and should be specified and further developed towards a localized crisis information sharing kit. On the basis of the localized kit specific information sharing solutions can be set up in order to create information marketplaces for response and recovery whenever crises occur.

This research is expected to contribute to our understanding how to design situated information sharing solutions for industrial crisis management. However, it tackles only one facet of the complexity inherent in industrial crisis management which is the *approach* towards creating the best possible solution for a given environment and crisis situation. Other aspects such as data accessibility, system interoperability, cloud-based components, information integration, semantic standardization are essential for implementing solutions, but the development and/or improvement of these is outside the scope of this research. Rather we seek to test to what extent stakeholders in charge (who are not ICT experts) find the vision of an information marketplace and the components of the 'information sharing kit' (including guidelines) helpful to create information sharing solutions that serve their needs. Insights from this research are expected to inform disaster preparation in practice, especially in ICT empowered community settings such as smart cities, and to identify more clearly the (research) needs for standardization in disaster-related information management and integration.

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