Less is more - Some cautions regarding mindless use of ICT in emergency management

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LESS IS MORE
- SOME CAUTIONS REGARDING MINDLESS USE OF ICT IN EMERGENCY MANAGEMENT

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ABSTRACT:
Emergency management practice can be supported by ICT in many ways, and numerous ICT-based systems are available that offer support in the different phases of emergency management. Yet, many such systems do not provide as much support to emergency management as expected or wished for. In some situations they may even compromise emergency management performance, due to suboptimal adaptation to the people who use them. This paper describes aspects of human functioning that should be considered in the design of ICT-based emergency management support systems, and points out why they matter. This is illustrated with examples of GIS in emergency management. The paper also briefly sketches how better adjustment to end users can be incorporated into the design of ICT-based systems for emergency management support. It is recommended that human factors are properly considered in both the design and operational phases of ICT-based emergency management support systems, which can be realized through cooperation between experts in emergency management, human factors and GIS.

KEYWORDS:
Decision making, design, emergency management, GIS, ICT, support system

1. INTRODUCTION

We live in times of Big Data. To collect, store, cross-reference and analyze vast amounts of data has become possible, and tools to perform the operations and present results have become so affordable that their use is rapidly increasing. For the field of emergency management this offers promising possibilities to process vast amounts of data. For example, the use of crowd sourcing and micro sensors enables quick access to spatial field data from areas uncovered by stationary monitoring networks, aerial photos or remote sensing, and analyzing content in the boundlessly expanding databases available today may inform risk and vulnerability analysis activities.

Big Data, cheap and available ICT solutions, and access to almost unlimited amounts of information can help intelligent, effective emergency management action. However, this requires heedful system designs, if not to instead impair emergency management performance. In this paper we will examine some of the reasons behind that dual nature of ICT use in emergency management, and point to possible ways to overcome the challenges.

2. EMERGENCY MANAGEMENT AND HUMAN DECISION MAKING

Emergency management is often described as having different phases or functional modes, often in the range between three (before, during and after) and eight different stages (FathiZahraei, 2015; Ahmed, 2015). One of the most implemented classification schemes divides emergency management into four stages: mitigation, preparedness, response and recovery (McLoughlin, 1985). Sometimes the logic is explained as a before-stage of preparations, a “hot” phase of managing ongoing events, and a recovery-phase when time pressure decreases again. In the cold phase before a disaster (or rather between disasters) long-term assessment, planning, forecasting and management can take place (Cova, 1999). This includes such activities as analyses of risks and vulnerabilities, educating people at risk and actions that prepare for hot phase emergency management. Ideally, lessons should be learned from a hot phase so that transfer to the mitigation or management of possible future hot phases is enabled (Borell & Eriksson, 2008, 2013).

As virtually all human activities, emergency management is dependent upon continuous decision making. Although central in all phases of emergency management, the criticality of effective decision making might become extra salient during hot phases. Understanding and designing for human decision making is therefore utmost important in preparations for emergency management.

Human decision making is limited by the information available, human cognitive capacity, and time. Such bounded rationality (Simon, 1996) becomes apparent in hot phases of emergency management, where emergency managers shall use limited, uncertain data, process it in real time, and arrive at intelligent choices of actions. An emergency manager has to answer such questions as: What are the future implications of the current state? What interventions are necessary? What are the implied decisions to be made? What actions are to be taken? (Harrald & Jefferson, 2007) That is what an emergency management decision support system should facilitate. However, it is not easy to decide what data is appropriate for a support system to process and present to successfully improve emergency management performance. The appropriate design of such decision support systems requires knowledge about what happens inside the emergency manager's mind. The following paragraphs outline some general aspects of the mental processes relevant in the enactment of hot phase emergency management.

Any intelligent activity requires that one grasps the situation one is facing. Both the process leading to such understanding and the product of it is often referred to as situational awareness (Salmon et al., 2008), and has a lot in common with the concept of (situational) sensemaking (e.g., Weick, 1995). Sensemaking and the construction of situational awareness is more than just a set of data, as it requires mental processing operating on both current sensory input and memories from past experiences. Situational awareness can be defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future (Endsley, 1988, p.97)". Situational awareness involves more than being aware of numerous pieces of data, and requires both a more advanced level of situation understanding and a projection of future system states relevant for the individual's higher level goals (Endsley, 1995). The formation of situational awareness encompasses both top-down decision processes, where goals and plans direct which aspects of the environment are attended to, and bottom-up processing, where patterns in the environment might suggest changes of plan or of goals (Endsley, 1995). The perception process is a function of contextual information (data), experience (memories), and cognition (mental processing) (Harrald & Jefferson, 2007). Thus an emergency manager receiving data has to perceive it, which includes supplementing it with a meaning component.

The use of perceptually driven bottom-up mental processes are key to efficient human performance in such demanding situations as hot phase emergency management decision making. As a person repeatedly encounters a specific type of problem, solutions to that type of problem are stored in long-term memory, and can later be retrieved rapidly and effortlessly (Logan, 1988). The resulting automated mental processes are fast, effortless and autonomous (Logan, 1988). The performance of emergency managers can be supported by automation of appropriate mental processes.

Rasmussen (1983) suggested the SRK-model for human cognitive performance, distinguishing the Skill-based, Rule-based and Knowledge-based levels of information processing and problem solving. Put simply, human response to a certain situational stimuli depends on how its degree of familiarity is assessed. If found so common that it has undergone automation, a skill-based feed-forward response process is executed, that generates a series of mental and motoric actions outside of conscious control. If a situation is not found to be so well known that an immediate, automatic response pattern can be executed, a pattern matching to situational ques is performed to search for stored behavioral rules. Such rules are simple combinations of requirements that are compared to the presently perceived situation, and feed-forward response sequences that have proven successful in similar situations. If no rule is found, attention has to be directed to the situational cues, which then are processed at the Knowledge-based level. Then effortful situational analysis is required, in an attempt to make sense of the immediate situation through analyzing it with models constructed from combinations of stored concepts and feedback from actions taken. At the knowledge-based level of processing performance is strongly affected by strict limitations of bandwidth, human working memory capacity and relatively slow conscious operation. From Rasmussen's (1983) SRK-model one can deduce that for any given role as many tasks and situations as possible should be anticipated and practiced for, to achieve suitable mental automation, so that the strictly limited resources for conscious, knowledge-based on-line problem solving necessary for strategic management are reserved for just that, and not used up by tasks that could have undergone automation.

When working under stress, human cognitive capacity is typically decreased, with a narrowed attentional span, diminished working memory and impaired strategic control over conscious mental processing (i.e., control over K-level activity in the SRK model) (Reason, 1990). People working under stress rely even more on highly automated responses (related to the S and R levels in the SRK model). The time-pressure, uncertainties and high stakes involved in emergency management puts extra demands on designing the working environment for emergency managers with human factors in mind, not overloading emergency managers with too much or un-timely presented information.

All intelligent action requires that the most relevant aspects of a situation are discerned and acted on (Bowden & Marton, 2004). For emergency management – as for most other activities – it is not trivial to identify the most important aspects, valid across all emergency scenarios. Even in specific cases it might be impossible to arrive at a definite set. This poses great challenges to the design and implementation of emergency management support systems, since the data entities they preferably should process are hard or even impossible to identify prior to a specific hot phase.

Beyond the mental requirements of the single, individual emergency manager there are yet more aspects that need to be acknowledged in the design of support systems. It is not enough that every individual person engaged in emergency management grasps what is going on and forms a personal situational awareness. For coordinated work, some degree of shared situational awareness is also needed (Seppänen, Mäkelä, Luokkala, & Virrantaus, 2013). When people are to work closely coordinated, performing demanding tasks in a complex and dynamic context, success relies partly on the degree of collective mind (Weick & Roberts, 1993) manifested.

We can conclude that the work process of emergency management, especially from a decision making perspective, puts demands on the design of the overall working situations regarding, for example, the division and coordination of tasks, handling of data and communication. Data served to emergency managers need to meet the requirements of decision making and action, i.e., completeness, timeliness, accuracy and consistency (Harrald & Jefferson, 2007). When designing for emergency management the total organization should be considered, including work processes and tasks, ICT-based support systems, competence profiles for individuals, etc.

3. A MODEL OF THE MAN-MACHINE-SYSTEM IN ICT-BASED EMERGENCY MANAGEMENT SUPPORT CONTEXTS

A rudimental model of the connection between human and ICT system is illustrated in Fig. 1, showing the control loop where input from one element in the system is processed by another element, which output becomes input to the first part, and so on. As mentioned above, in emergency management the processing on the human side can be viewed as concerning decision making. The point with having an ICT-based support system is that it should improve decision making performance.

Om the right side of Fig. 1 the ICT part of the system processes data. Central questions there concern such aspects as what data to gather, how to process data, and in what form and when to present data. For data that are presented the degree of processing and the levels of abstraction and aggregation are important to consider.

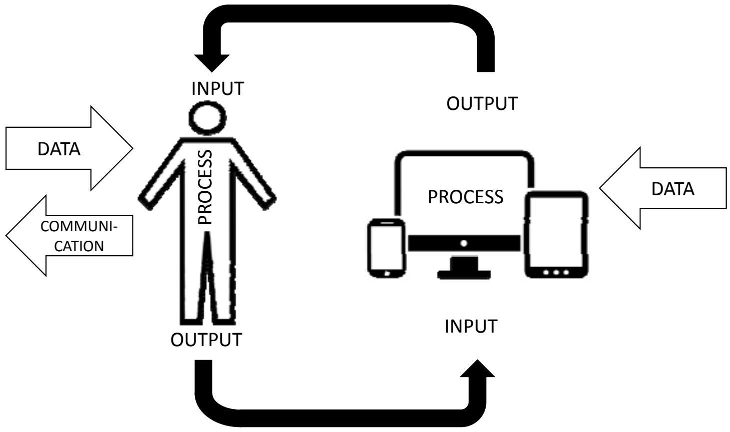

Figure 1 Control loop connecting human and ICT in an interactive system

In the next section some of the possibilities and possible pitfalls with ICT use as emergency management support are described, with examples from GIS.

4. THE ROLE OF ICT AND GIS IN EMERGENCY MANAGEMENT

Although emergency management is an important societal responsibility gaining massive public support its resources are limited. Thus there is a need for emergency management support tools, such as ICT-based decision support systems, that increases performance in all emergency management phases. Such a support tool, which has gained popularity in recent decades, is Geographical Information Systems (GIS). GIS were designed to support spatial decision making, necessary to succeed in many instances of emergency management (Cova, 1999).

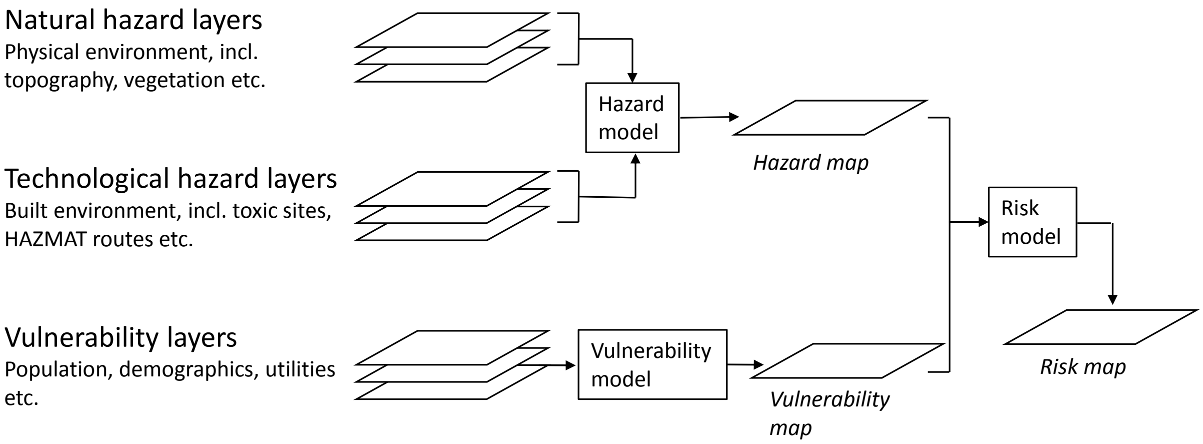

Figure 2 One approach to GIS use in emergency management (Adapted from Cova, 1999)

GIS are used to capture, store, analyze and visualize spatial data. In emergency situations there are many spatial elements to take into consideration: position of population at risk, location of resources, evacuation routes, damaged areas etc. The principle is illustrated in Fig. 2. Thus GIS can be used to identify vulnerabilities (people or facilities) that may be subject to potential hazard, identify sources of hazards (e.g., materials or energies) and keep track of resources (people and equipment) that can be used in emergency management (Gunes & Kovel, 2000). Examples are given in Fig. 3. Emergency managers typically need to grasp situations, identify possible scenarios and consider alternative courses of action, which are activities that can be aided by the use of GIS. Many systems do not only enable visualization and analysis of the present state but also projections of possible future scenarios and effects from various actions, handling both unsystematic risk scenarios (affecting only a specific group) and systematic risk (an emergency that strikes the entire society and makes major disruption to service operations and infrastructure) (FathiZahraei, 2015).

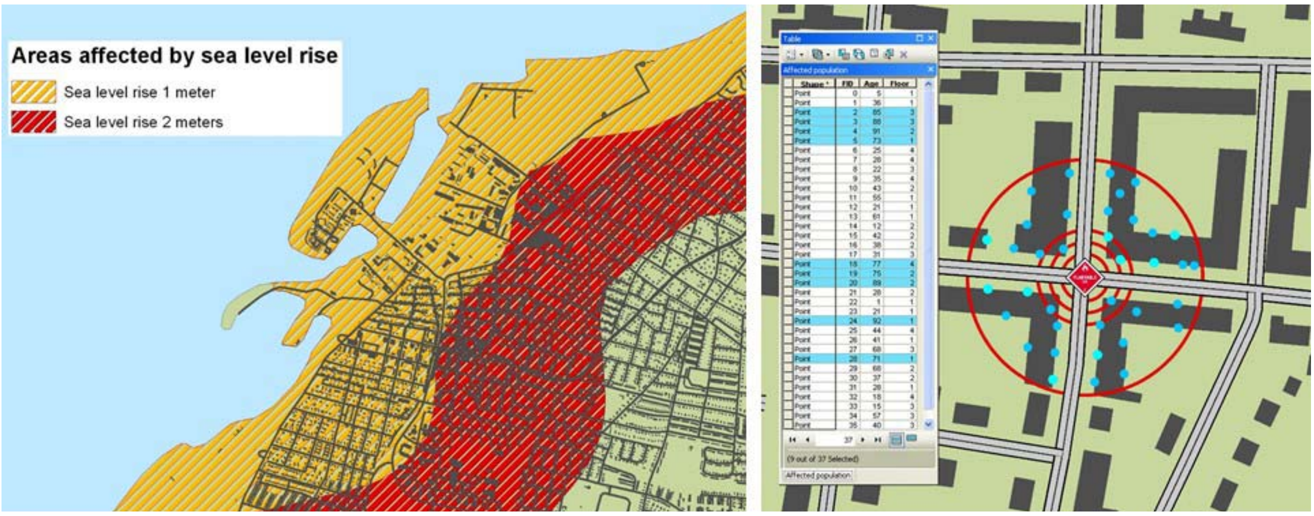

Figure 3 Examples of spatially coded data useful in emergency management. *Left side*: Potential flooding zones in a coastal city in Sweden. *Right side*: Vulnerable population in the buildings surrounding a (fictional) accident with flammable material.

Emergency managers typically analyze situations and suggest actions to others, within or outside the formal emergency management organization. GIS' ability to quickly visualize data and scenarios and thus potential problems to emergency managers as well as providing "non-technical" personnel with visual information and an interpretational image of the situation has great potential. Likewise ICT can be used to assist the (collective) sensemaking process necessary for establishing (shared) situational awareness within the social network of people involved in a case of emergency management. These advantages in combination with the increasing availability of vast amounts of inexpensive spatial data has thoroughly integrated GIS in emergency management. Yet, there are many aspects that need to be considered of ICT-based support systems shall be likely to improve emergency management performance.

Time and space are key issues in emergency management. Data does not only need to be spatially accurate but also up to date or, when time is of the essence, with high temporal resolution, such as real-time changing weather conditions (wind directions, precipitation etc.) or time-activity pattern of a population. Reliable real-time tracking of the locations of everything useful in disaster planning and response is not realistic (Gunes & Kovel, 2000), and attempts at it should be used with caution. It is not within an ICT-system a comprehensive picture is needed, but in the minds of emergency managers. It is not enough with data stored in or visualized by ICT, if appropriate understanding in the human part of the system is not produced. The pacing

The development of cheap micro sensors, smartphones and positioning systems have enabled real-time data gathering through crowdsourcing, thus collecting a vast amount of data from locations and positions that might otherwise be inaccessible. Today the possibilities for anyone, anywhere at any time to send, receive and share information enables disaster information, possessed by local residents, to be accumulated and shared easily (Yamamoto, 2015). Despite these technological advancements the information's reliability, accuracy and suitability needs to be thoroughly addressed and considered. Frequently the data available to the decision makers is unreliable in the sense that it is either incomplete and/or uncertain in terms of accuracy and veracity (Frez et al. 2014). One must also bear in mind that working with vast data sets does not take away subjectivity; in deciding what will be measured, or taken into account in an analysis, interpretation and subjective perspectives are at play (Boyd & Crawford, 2012). Computers do not always present "the truth".

During emergencies there is a need for rapid decisions and the stress of the situation can foil ordinary channels for communication and management, especially during hot phases with their time pressure and emergency managers engaged in real-time decision-making, trying to choose appropriate responsive actions to the unfolding emergency scenario. Apart from the stress of the situation there are often unfavorable working conditions that complicates the data mining further, stressing the need for more automated systems for different procedures, such as: identification of tasks which can be performed by control systems, automatic detection of input using sensors and automatic decision-making based on received data using artificial intelligence (Ahmed, 2015). A technology that can apply these automations are more likely to be implemented successfully but is also more vulnerable to failures in the system.

Emergency management is typically a multi-disciplinary endeavour, requiring many types of data with spatial and temporal attributes that should be available to key players in the right format for decision making (Bhanumurthy et al. 2015). Although GIS can be used for integration and dissemination of spatial information that aides the emergency management process (Cova, 1999) there is often an enormous amount of geospatial data of all kinds and formats. It is often hard to find the right data at the right moment by the people who need the information for rescue work and recovery operations (Bhanumurthy et al. 2015).

Another concern with digital systems and major databases designed to support emergency management is that they generally consist of a vast amount of sensitive data that needs to be protected from unauthorized and illegitimate use. Haddow et al. (2008) suggest that these systems should take measures such as: implementation of authentication protocols, assigning user privileges and verification of access request to ensure legitimate use. Unfortunately these measures are sometimes in conflict with the need to quickly provide a large number of people with information needed to assist rescue operations or to provide the population at risk with adequate information in order to take protective measures. This is of special concern when visualising spatial data. Although the data in itself might only be presented as spatial entities (dots, lines or polygons), without sensitive attribute data visually connected to them, the spatial information in itself, or in combination with other spatial entities or thematic maps/aerial photos etc., might violate integrity issues or reveal sensitive information. Thus the strength with GIS in emergency management could also be turned to its disadvantage.

5. ANALYSIS AND DISCUSSION

We have seen some of the capacities and limitations regarding human (cognitive) functioning acknowledged within the field of human factors, briefly listed some of the special demands for effective emergency management, and seen examples of how ICT-based emergency management support systems can be used. Intertwined in these descriptions we have presented some of the potential pitfalls with too demanding (interfaces to) ICT systems or too high reliance on ICT-based data management in emergency management. The grand question of how to tackle these challenges will be approached below.

In designing the total system (work processes, ICT-support etc.) for emergency management, general principles of design may be applied. A general model for such design of artefacts is the design logic of *hierarchical decomposition* described by Simon (1996), where one starts with the purpose of what is to be designed, continues to formulate a set of functions that if satisfied would mean that the purpose is fulfilled, then recursively breaks each function to a set of sub-functions, until a level suitable for concrete implementation is reached. The approach allows for variation in partitioning of the problem space, as long as the ultimate purpose is fulfilled. The use of abstraction hierarchies in such hierarchical problem structuring allows us to manage complexity (Rasmussen & Lind, 1981) by attending to a subsystem at a time without considering more than locally relevant parameters.

In the design or evaluation of ICT-based emergency management support systems it is paramount to choose the correct system purpose for assessment. Too often emergency management decision support systems are designed to collect and transmit as much data as possible, and then summarize it into reports that are supposed to facilitate decision making (Harrald & Jefferson, 2007). Such negligence of human capacities and limitations sometimes result in poor emergency management performance. Massive amounts of data is useless to a decision maker unless processed into a comprehensible set of information. The performance of a risk management support tool should not be judged on how much data it processes or displays, or on how many aspects of the situation it integrates data from. Rather, as Zerger (2002, p.287) points out, “the ultimate success of a risk management project should be assessed in the context of improved decision-making".

Allowing ICT-based data processing overshadow human sensemaking processes is likely to result in information overload rather than situational awareness (Harrald & Jefferson, 2007). It is the overall performance of the socio-technical system that matters. Too much information, or delivered untimely or in a way not optimizing comprehension, poses unnecessary constraints on human (emergency manager) performance.

What data the emergency manager is likely to need for optimal work performance is the key question in total system design. In the design of a specific emergency management process and its support systems, a number of important questions need to be asked. For example, which are the foreseeable meaningful categories of data entities? How generic can they be? What can ICT support contribute to emergency management decision support in this case? What data should be gathered, operated on and presented, considering the capacities and limitations of the human emergency managers operating in the system? What levels of abstraction and aggregation should be used in ICT-based data processing?

Possible strategies to use in the design of more appropriate and/or flexible ICT-based emergency management support systems can be to:

- Choose an appropriate degree of ICT-based processing (Challenge – To have neither too much "raw" data nor too processed and condensed info)
- Offer user-controlled degree of processing
- Adjustable filters (let end users choose what kinds of info to process and present)

To connect different ICT systems and enable data sharing is sometimes assumed to enable shared situational awareness. However, that view ignores the meaning aspect of data (Harrald & Jefferson, 2007). Having access to the same data does not lead to the formation of identical situational understandings, because the individuals' specific, personal perception processes use different sets of earlier experiences and thus yield - more or less - different results.

Another challenge lies in the emergency management requirement of real-time information and temporal detail, colliding with GIS-based tools that tend to have spatial detail but lack reliable temporal (real-time) precision (e.g., Zerger & Smith, 2003).

Integrated emergency management (McLoughlin, 1985), an all hazards approach and comprehensive emergency management (FEMA, 1996) are examples of attempts at generic models for organizing emergency management that can deal with (almost) any emergency situation. Since we cannot know exactly what emergency situations that will become manifest and require hot phase management, preparations for a wide and uncertain set of possible scenarios is required. Because some of the situational aspects needed to consider for successful management will be unique for each particular emergency scenario it is impossible do decide on a finite set of data categories that will be sufficient to consider in the management of all emergency situations. This poses great challenges to the design of emergency management decision support tools, and with a technology-centred approach to the design without sufficient consideration of human factors one might end up with far from optimal design solutions.

Another set of risks with extensive ICT use in emergency management is the dependence on certain technologies, which introduces vulnerabilities. Because ICT support systems can fail - as they often do in times of crisis – emergency management needs contingency plans and should retain the ability to monitor and manage hot phases without hi-tech support systems. On a societal level, the dependence on complex socio-technical systems for some of the fundamental functionalities (such as power and fresh water services, economical transactions or transportations systems) has gained much attention among researchers and practitioners. Big Data and ICT-based systems brings many advantages as they offer society valuable possibilities, but the potential mal- or non-functioning of systems needs to be considered and prepared for, since all complex socio-technical systems fail sooner or later (Perrow, 1984).

6. CONCLUSIONS

The main point in this paper is that the effective use of ICT-based emergency management support tools requires that human factors are properly considered in both the design and operational phases of such systems. Otherwise emergency management performance may be severely compromised.

The need for human-centred design should be acknowledged and human factors should be considered in the design of emergency management decision-making support systems and emergency management work processes. This may be realized through cooperation between experts in emergency management, human factors and GIS.

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