A Psychological Framework to Enable Effective Cognitive Processing in the Design of Emergency Management Information Systems

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Abstract: Human cognitive processing and decision making are essential aspects in emergency management. Emergency situations imply additional demands to information processing. To meaningfully support decision makers in emergencies, a comprehensive understanding of the human perception and decision making processes and their underlying principles is required in the design of Emergency Management Information Systems (EMIS).
This paper presents a psychological framework that models the stages and components of decision making in the context of emergency management. To this end, psychological research on human perception and information processing, knowledge and competence modelling, human judgement and decision making, individual and situational factors, stress, and self-regulation are identified as important compents of the framework. The psychological framework represents a comprehensive model of decision making of emergency managers, for a better understanding of the involved cognitive processes and influencing factors on the person level and on the context level. The paper posits the framework as a guide in the identification of requirements for emergency managers during systems analysis.
This comprises systematically describing decision tasks in emergency situations and identifying needs for supporting them. The knowledge on human perception and decision making represented by the framework can also be used to inform the user interface design of the EMIS. It may also inform the evaluation of EMIS as it provides a theoretically founded representation of relevant aspects of human-computer interaction, which facilitates the identification of success indciators to be addressed in user-centred evaluation.
The framework furthermore supports the design and implementation of training programmes through the differentiation and modelling of knowledge and competence relevant in emergency decision making. To demonstrate the application of the psychological framework in the design, development, and testing of EMIS a set of concrete design principles as well as exemplary paper prototypes applying these principles are presented.

Keywords: emergency management, information system, psychology, decision making, information processing, decision support, design principles, system design

1. Introduction

A successful response to an emergency highly depends on whether information is processed and decisions are taken in an effective and timely manner by emergency managers. Human cognitive processing in emergency situations is different from cognitive processing in business or other scenarios and poses additional challenges. This needs to be taken into account when aiming at supporting information processing and cognitive functions in this context. Emergency management involves acting in situations of high complexity and stress; emergency managers must "act under conditions, in which lives may be at risk, high-value property may be at stake, and chances for escalation of damage may be high" (Comfort & Wukich, 2013, p. 54). Decision making is an essential aspect of emergency management and a successful response to an emergency situation highly depends on whether decisions are being taken in an effective and timely manner. Decision making in emergencies cover a broad range of decisions to be taken, from declaring a state of emergency, issuing an evacuation, to decisions on strategic or tactical level, depending also on the decision maker's level in the command structure. Acute emergency situations represent decision environments that are dynamic and complex, due to a large number and interdependence of variables involved, dynamics, uncertainty of the situation, information overload or lack of information, time pressure, risk, plurality of goals, and multiple players involved (St.Pierre et al., 2008).

Emergency Management Information Systems (EMIS) thus have a critical role in supporting emergency decision makers. A comprehensive understanding of human decision making and its background factors and processes becomes key to the design of EMIS. In pursuance of this, this paper presents a psychological

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framework which aims at contributing to and enriching the knowledge base on decision making in emergency management. Our framework has been defined to better understand how emergency decision makers perceive information and how to effectively represent information to support them. It consolidates research from different psychological disciplines and contextualises them in the specific application area of emergency situations. It provides a theoretical basis for further empirical research. This psychological perspective is necessary to inform the analysis, design, development and testing of EMIS. Thus, the framework forms a bridge between psychological research and information system research on for emergency management.
The psychological framework presented in this paper is an updated and extended version of an earlier framework modelling decision making in emergencies (Steiner, Nussbaumer, and Albert, 2015). The original framework has been elaborated upon based on an additional literature review and desktop research, empirical research and end-user and expert feedback and is presented in detail in the remainder of this paper.

This paper is structured as follows: Section 2 gives a literature overview of relevant psychological aspects. In section 3 the psychological framework and its different components are described. Section 4 outlines how the psychological framework can be meaningfully applied in the field of information system research. Section 5 presents a set of design principles and example paper prototypes that translate the theoretical knowledge into concrete system design implications and decisions. Section 5 finally summarises the main ideas and provides an outlook to future work.

2. Literature Review

Modern emergency management relies on information systems technologies and makes advantage of many functions and tools typically found in information systms (van De Walle, Turoff, & Hiltz, 2010). For example, geographical information services, knowledge and document management services, resource information services, and weather services are typical services used for Emergency Management Information Systems (EMIS). While this technical background is well described in literature, there is still a lack of understanding of the influence of psychological and human factors on the use of such systems. Thus, this section focuses on psychological aspects related to emergency management. These are subsequently used to build a psychological framework for emergency management in the context of information systems.

The psychological framework integrates several strands of psychological research that are relevant for decision making and support in emergency situations. This section briefly introduces the theoretical background and gives a concise summary on aspects of the topics relevant for and underlying the S-HELP psychological approach and interface design guidelines.

The topic of human perception in cognitive psychology refers to how information from an environment is selected and processed (Anderson, 1990). The broad term of perception refers to "apprehending objects and events in the external environment – to sense them, understand them, identify and label them, and prepare to react to them" (Zimbardo & Gerrig, 2002, p. 135). Thus, perception can be defined as the process of recognising (being aware of), organising (gathering and storing), and interpreting (binding to knowledge) sensory information (Goldstein, 2010). Perception deals with the human senses that generate signals from the environment through sight, hearing, touch, smell, and taste. It is the process by which we interpret the world around us, forming a mental representation of the environment.

Gestalt theory can explain structural organisation in perception, i.e. the way we perceive and recognise objects and patterns (Goldstein, 2010). The central assumption is that human perception is holistic; the perception of a pattern or form is not simply explained by the sum of its parts, but is more than that. A core part of the Gestalt theory is the so-called "Gestalt principles", which try to explain how humans organise individual elements into groups. Originally, they were defined as "Gestalt laws", today they are considered as principles or heuristics. They serve as "rules of thumb" in perception and help to explain perceptual organisation, but they do not allow for precise predictions. The Gestalt principles were initially conceptualised for visual perception, but they also work for other senses (e.g. auditory perception), and are therefore considered as a general descriptive framework and explanatory instrument in human perception. Examples of Gestalt principles are the similarity principle (similar things are perceived as grouped together) and the proximity principle (things that are near each other are perceived as grouped together).

Knowledge is an essential construct and part of human cognition and information processing. In the analysis of cognitive processing and of how knowledge is represented in the mind, traditionally two main types of knowledge are distinguished in cognitive psychology. These are declarative and procedural knowledge (Anderson, 1990). Declarative knowledge encodes the (conscious) factual knowledge. Procedural knowledge consists in knowledge about how to do things and is displayed in behaviour (problem solving) and refers to (mostly unconscious) cognitive skills.

Different approaches for modelling knowledge have been developed in psychology. The ACT-R (Adaptive Character of Thought - Rational) is a production system theory for representing knowledge and how human cognition works (Anderson, 1993). It builds upon declarative (conceptual) knowledge and procedural (action) knowledge and represents them in a propositional network. Knowledge Space Theory (KST) is a theoretical framework for knowledge and competence modelling (Doignon & Falmagne, 1999). It is a powerful approach for structuring and representing domain and learner knowledge. In its original formalisation, a knowledge domain is characterized by a set of problems or test items. Due to mutual dependencies between the problems so-called prerequisite relations can be derived. The knowledge state of an individual is identified with the subset of problems that this person is able to solve. The subset of problems that this person is able to solve is called the knowledge state. While traditional KST is purely behaviouristic, Competence-based Knowledge Space Theory (CbKST) is a competence-based extensions of KST (Albert & Lukas, 1999; Heller, Steiner, Hockemeyer, & Albert, 2006). The basic assumption is the existence of latent cognitive constructs represented by a set of skills that provide a fine-grained description of the capabilities related to a certain knowledge domain. By identifying and modelling prerequisite relationships among the skills of a domain a competence structure can be built in analogy to a knowledge structure. Accordingly, a competence state is conceived as the subset of skills that a learner has available.

Self-regulated learning denotes an active, constructive process of learning that is directed by the learner (Puustinen & Pulkkinen, 2001; Zimmerman, 2000). Self-regulated learners take over control and responsibility over their learning, they direct and regulate their own cognitive and meta-cognitive processes within educational settings. Meta-cognition is the knowledge about one's own cognitive processes, strengths and limitations, characteristics of tasks, and learning strategies, which could influence cognitive performance (Flavell, 1979). Self-regulation does not play a central role in learning only, but is essential in everyday life, in general. Self-regulation relates to an area of psychological research, which incorporates work on diverse viewpoints, aspects and applications of self-regulation constructs, including self-regulated learning, self-control, volition, and self-management (Boekaerts, Pintrich, & Zeidner, 2000).

Decision making is a process that concerns people in many situations and include personal decisions (such as career decisions, romantic decisions, medical choices, and financial decisions) and professional decisions (such as in medicine, education, and accounting). Some of them are simple and straightforward, others are complex and risky, and involve a multi-step approach of judgement and decision making. Research in psychology has defined theories and models that try to explain how people make decisions and what factors influence their decisions (Plous, 1993; Newell, Lagnado, & Shanks, 2007; Ranyard, Crozier, & Svenson, 1997). Different types of decision theories have been elaborated (Bell, Raiffa, & Tversky, 1988). Examples are normative theories that try to model how decisions should ideally be taken, descriptive theories of decision making that identify principles and rules human apply in decision making and try to explain and predict decisions, prescriptive models of decision making that provide methodologies to help people make better decisions, and models of rational decision making that suggests and analysis of all possible alternatives and their consequences.

Decision making competence is a multidimensional construct and includes a range of key skills. Following a normative approach of decision making, usually four basic skills are distinguished, which are belief assessment (judging the likelihood of outcomes), value assessment (evaluating outcomes), integration (combining beliefs and values in decision making) and metacognition (knowing one's abilities) (Bruine de Bruin, Fischhoff & Parker, 2007). In a more general sense, Finucane and Gullion (2010) defined the ability of understanding information, integrating it in an internally consistent manner, identifying the relevance of information, and inhibiting impulsive response as the basic decision making skills. Decision making can also be considered as a multi-step process including the steps pre-decision (understanding the problem and identifying the decision to be made), decision (generating and evaluating alternatives, choosing among alternatives, and implementing the selected solution), and post-decision (identifying and evaluating the consequences of the taken and implemented decision) (Zeleny, 1982; Betsch et al., 2011).

3. The psychological framework

This section introduces the psychological framework of decision making in emergencies, which has been defined based on an integration of different fields of psychological research and translates these theoretical foundations to the specific area of decision making in emergency management. The framework describes and captures the cognitive processes, involved skills, relevant influencing factors, as well as intra- and inter-individual differences in emergency preparedness, response, and recovery, to meaningfully feed into the design of effective information systems for managing emergencies. Figure 1 presents an overview of the psychological framework. At its centre is decision making, which is broken down into different stages forming a cyclical and iterative process. Decision making is mediated by different aspects, which can be separated into two layers - aspects characterising the user of an EMISon the one hand, and aspects characterising the context (emergency and decision situation), on the other hand. The decision making process, as well as the person and context layer with their different aspects are explained in more detail in the subsections below.

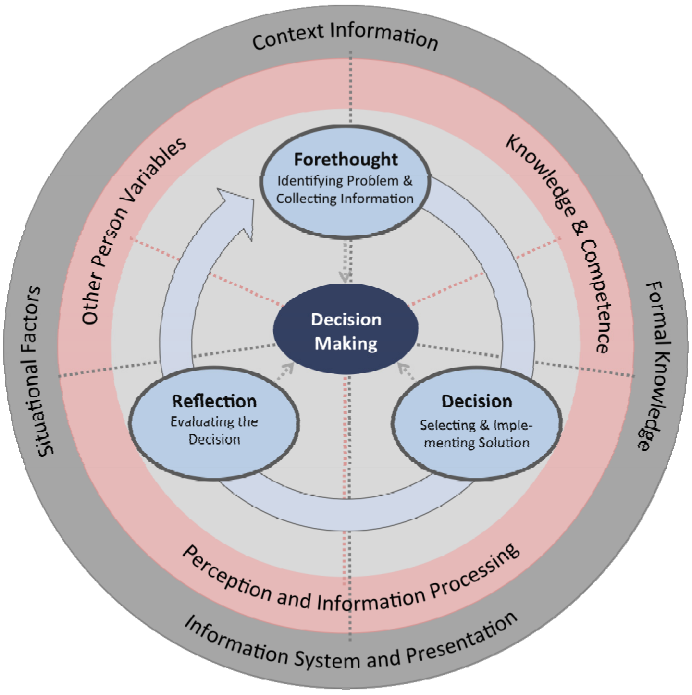

Figure 1: Psychological framework of decision making in emergencies (with the decision making layer at the centre, the person layer in the middle, and the context layer outermost).

3.1 Decision making process

Decision making involves making judgements and drawing conclusions on the basis of available evidence and knowledge. It covers activities of gathering information and analysing a situation, as a basis to choose between alternatives, picking one alternative and dropping the others, implementing and evaluating the solution. The characteristics of emergency situations, i.e. complexity, uncertainty, non-transparency etc., are experienced as obstacles in collecting and integrating information, and planning and implementing effective action.

Different theories have been devised in psychology and behavioural economy to model human decision making (for an overview see e.g. Koehler & Harvey, 2004) and aim at explaining and predicting decisions and defining rules of ideal decisions. Such models and rules of rational judgement and decisions are systematically implemented in computer-based decision support systems to support human decision making. In contrast to these outcome-oriented theories of decision making we take a process-oriented approach and model the process and phases of decision making, with the main goal of capturing relevant psychological aspects of human cognitive processing in emergency situations.

The process-oriented perspective on decision making is considered key when aiming at understanding and aiding decisions. A decision is not an action, rather it is a process carried out to solve a certain problem (Simon, 1977). The goal of decision support is not to provide a choice of actions or the optimal option. It is rather about understanding how decision makers collect and use information, in order to understand and assist

them. That can be done by integrating this understanding in decision support systems (Kamissoko, Zaraté, & Pérès, 2014).

Decision making, in terms of an explanatory framework, can be seen as a multi-step procedure; essentially, the process is defined by the following main stages: pre-decision, decision, and post-decision (Zeleny, 1982). These decision making stages parallel the process of self-regulation, which is usually described as a cyclical process of three phases – forethought, performance or volitional control, and self-reflection – and emphasises the role of meta-cognitive activities and skills (Zimmerman, 2000). Considering the decision making process as a concrete application of self-regulation makes evident the importance of metacognitive knowledge and regulation in decision making.

The core process of our psychological framework is therefore a three-stage model (See Figure 3) of self-regulated decision making in emergency situations:

- *Forethought (Pre-decision):* This phase refers to identifying the problem, i.e. an undesirable situation or condition (like a disaster) that exists or will exist in the future, and assessing this problem through gathering and judging information about the emergency situation.
- *Decision*: This phase involves exploring, developing, and evaluating alternative solutions to the problem identified, selecting an option on the basis of their evaluation, existing contingencies, and under consideration of outside factors (e.g. political, safety, financial, environmental, ethical), and implementing this solution.
- *Reflection (Post-decision):* The reflection phase consists of evaluating the solution, i.e. determining the results of the implemented decision and identifying whether the problem has been resolved or additional action is needed, whether the situation has changed, more resources are needed etc. This reflective/evaluative phase is essential, since it provides input and information for subsequent decision making (Kersten & Szpakowicz, 1994).

3.2 Person layer

3.2.1 Perception and information processing

Humans operate in a perception-action cycle: senses take in information from their environment, the mind does computations on these environmental stimuli, and the results of these guide subsequent goal-directed actions. A key aspect therefore is that the biological organism and information processing capacity is limited and humans must select from all the environmental stimuli available in a situation to which to attend to (Goldstein, 2010). This is particularly important when considering emergency situations, where often a multitude of information on many different variables is available and relevant information needs to be distinguished from less relevant one. Furthermore, information processing capacity and focus of attention are further decreased under stress, which if often prevalent in emergency management, especially in the response phase to acute incidents (Maule, Hockey, & Bdzola, 2000; Kowalski-Trakofler & Vaught, 2003).

Perception and information processing have an influence on the self-regulated decision making process for two reasons. First, human perception and human processing influence the way in which information and graphics are interpreted. Second , the way information is presented and visualised affects how it is perceived and understood by humans. Gestalt psychology (Koffka, 1935; Goldstein, 2010) can help to understand perceptual organisation, i.e. the way objects and patterns are perceived and recognised. The well-known 'Gestalt principles' explain how humans organise individual elements into groups. The principles of good figure (simplicity), similarity, closure, proximity, and common region are among the most well-known principles (see Figure 2 for examples).

Many decision makers exhibit a tendency of trying to collect more information than would actually be required for making a good decision; this necessarily means additional processing time. It may even lead to information overload, such that the entirety of available information cannot be managed and evaluated appropriately, leading to selective use of information and missing of pertinent information. In addition, due to different physical or cultural background, it should be taken into account that interindividual differences in perceptual skills may potentially lead to different perceptions of visual items. An appropriate presentation format of information is therefore important (see section 2.3.1) to support information processing and decision making.

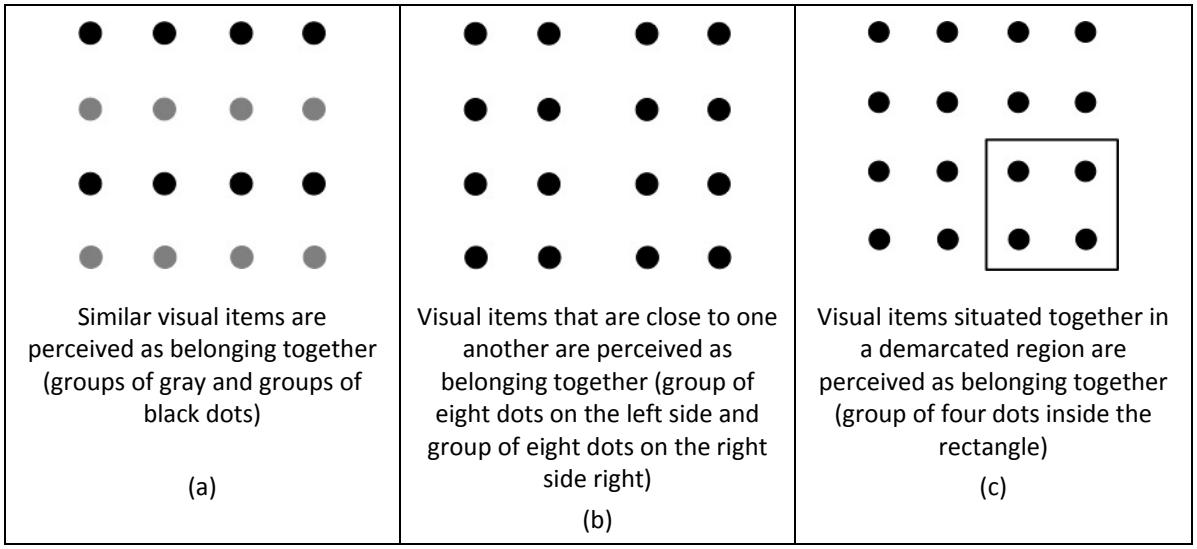

Figure 2: Example illustrations for the Gestalt principles of (a) similarity, (b) proximity, and (c) common region

3.2.2 Knowledge and competence

The knowledge and competence of decision makers in emergency management includes domain-specific knowledge on emergencies and emergency management, as well as decision making knowledge and competence. Domain-specific knowledge relates to previous personal knowledge (cf. Diniz, Borges, Gomes, & Canos, 2005) that is embedded in an emergency responder's mind and has been acquired during past experiences of emergencies, trainings and simulations on emergency management procedures etc.

Knowledge and competence on decision making refers to meta-knowledge and capabilities (skills) involved in the self-regulated decision making process. Decision making constitutes an area of critical thinking skills that is considered essential nowadays. Decision making competence is a multidimensional construct including a range of different key skills (Finucane & Gullion, 2007; Mincemoyer & Perkins, 2003). In the context of our psychological framework a collection of decision making skills has been defined in alignment with the stages of decision making. An initial skill set has been developed based on literature and desktop research. To validate this competence model, an expert review applying the Delphi method (Barber & Tietje, 2004; Hsu & Sandford, 2007) has been conducted. Based on this expert validation and feedback the decision making skills have been refined to form an agreed competence modelling covering 16 skills grouped into the three decision making phases (see Figure 3). The expert validation process process consisted of two phases and included eight experts in decision making and psychology. In the first phase the experts were asked individually to review each of the competences according their appropriateness and granularity level, and to add missing competences. Based on these results a modified list of decision making competences was created taking into account the feedback from the experts. In the second phase the experts got the modified list and were asked again to review each competence according to their description and appropriateness. Using this feedback the final set of decision making competences has been created.

Another relevant aspect of knowledge or competence refers to a decision maker's ability to handle and use an information system for emergency management. Possessing the necessary knowledge about the system and digital literacy skills to deal with it are crucial for effectively using the system as supporting tool in the decision making and emergency management context.

The three types of knowledge and competence (i.e. emergency management competence, decision making competence, and information system competence) are applied in concert for effective emergency management. This mirrors the competence model elaborated in the EU-funded project Responsive Open Learning Enviornment (ROLE), where domain knowledge and related skill, the ability to use e-learning tools, and self-regulated learning skills have been distinguished (Nussbaumer, Dahn, Kroop, Mikroyannidis, & Albert, 2015).

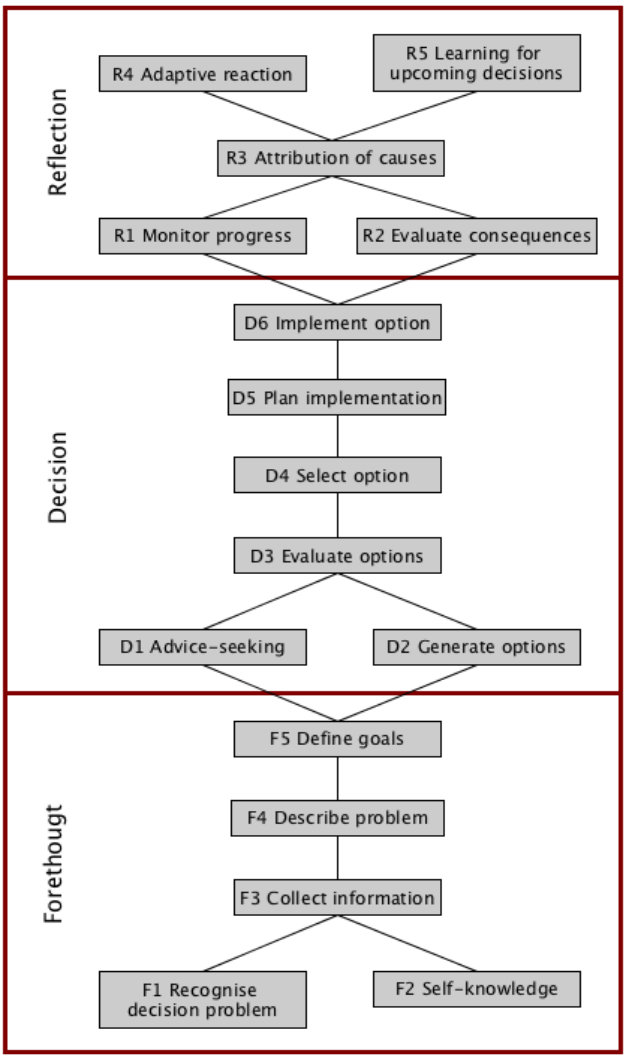

Figure 3: Decision making skills and their structure

For a systematic approach to knowledge and competence modelling, we suggest using Competence-based Knowledge Space Theory (Doignon & Falmagne, 1999; Heller et al., 2006), a psychological set-theoretic framework for modelling domain and individual knowledge. This theoretical approach establishes a structure on a knowledge domain by capturing the inherent structural dependencies (prerequisites) between the items or skills of a domain. This kind of competence structure has been elaborated for the decision making skills defined and represents the sequential steps and their dependencies in the decision making process (see Figure 3).

3.2.3 Other variables related to person characteristics

Person variables are characteristics related to individual or groups of decision makers, i.e. individual differences affecting judgement and decision making (Appelt et al., 2011). While 'perception and information processing' (see section 2.2.1) and 'knowledge and competence' (see section 2.2.2) already cover comprehensive aspects for the characterisation of decision makers, there are other person variables, like personality factors, previous experience, flexibility, emergency management level etc. that have an influence on the decision making process and the actual decisions taken by a person in emergency management. These variables may be categorised into two main categories relatively stable individual characteristics (traits) and temporary changing states. Good decision makers, in general share certain characteristics, like a deep knowledge and understanding of all factors involved in the problem situation (situation awareness), good self-knowledge, appropriate strategies to overcome their cognitive limitations, perceptiveness, good communication skills, good judgement ability and calculated risk taking, self-confidence, and creativity under stress (Shanteau, 1988). In emergency situations, experience has been identified as one of the most influential

factors affecting decision making. Experience facilitates the correct perception and analysis of risk and rational decision-making. Other relevant factors are education and training, which provide a feeling of security in an emergency situation.

3.3 Context layer

3.3.1 Information system and information presentation

Information presentation factors may influence time efficiency, accuracy, or strategy selection during decision making. The modality and structure of presentation (e.g. images vs. text), for example, have been shown to influence time efficiency of decisions (e.g. Aminilari & Pakath, 2005). If information is structured meaningfully and in line with the decision task, this positively affects the perceived value of information and time efficiency. In the context of emergency management, information is usually presented to decision makers via an information system such as a warning system or , decision support system). A careful consideration of information presentation via the user interface and visualisations provided by the system is therefore essential when aiming at supporting decision makers in their tasks.

High stress conditions lead to reduced information processing capacity (Hancock & Szlama, 2003). Thus, a reduced number of information sources used and inhibition of new information sources should minimise the information dispersal over multiple sources and new information should be linked to existing data. Where possible, integrated displays should be used, in which different information is brought into a coherent whole. Data presented should not require transformation, since this puts additional cognitive load in processing information and might be misinterpreted or disregarded under high stress level. Multimodal presentation of information in user interfaces is more effective for perception and information processing than unimodal approaches are (Koglbauer, Hohenberger, & Steger, 2013). In addition, Gestalt principles have been increasingly acknowledged and taken up to improve user information presentation and interface design (e.g. Chang, Dooley, & Tuovinen, 2002; Johnson, 2010; Gómez Reynoso & Olfman, 2012). Furthermore, the theory of affordances may inspire the way information and interaction elements are represented. Affordances are clues to operations of objects that are perceived in a direct and immediate way without any deeper cognitive processing (Kaptelinin, 2014).

Human-computer interaction in emergency management can be described through a triangle of the user, the system, and the information (see Figure 4 for an illustration).

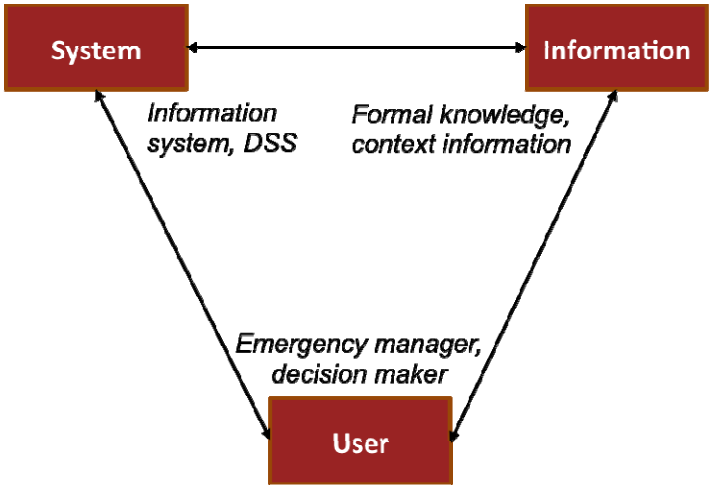

Figure 4: Interaction triangle of human-computer interaction in emergency management

This triangle spans the two layers of the psychological framework (cf. Figure 1). The user is represented by the person layer; he/she perceives and processes information, carries out actions of information exploration and evaluation and makes decisions. The system and information are located on the context layer. The system refers to the technical infrastructure, user interface, services and tools. Information refers to the data and information given to the user, which is visualised and made accessible through the system. Information is thereby distinguished into formal knowledge (like standard operating procedures) and contextual information about the current emergency situation (see sections 2.3.2 and 2.3.3).

3.3.2 Formal knowledge

Formal knowledge is information or knowledge relevant to the decision and coming from a reliable source. This consists of information and documentation of emergency management knowledge (domain knowledge) and includes, for example, emergency response plans, maps etc. (Diniz et al., 2005). For prudent decision making emergency leadership and response teams need to have access to and need to be familiar with such formal knowledge, like standard operating procedures designed and defined to maximise response to disastrous events and minimise the impact of those events.

2.3.3 Context information

Context information represents data about the current emergency situation. It is generated by the emergency itself (e.g. incident location, extent of a fire etc.) or the response to it and corresponds with what Diniz et al. (2005) describe as 'current contextual knowledge'. Decision making is challenged by the instability and dynamics of the situation that is given in an emergency, which mean uncertainty for decision making. Adequate, timely, and continually updated context information is therefore crucial. Any decision taken and implemented will influence and change the current context information forming the basis for further decisions.

3.3.3 Situational factors

Situational factors are characteristics of the decision situation (unlike context information, which is related to the emergency in a narrower sense). These include time pressure or available time scales, accessibility of information, organisational policies, lack of information or conflicting information, information overload, ~~persons/~~stakeholders involved, and socio-political factors or pressures. Another relevant situational factor is the approach to decision making including individual decision, individual decision with consultation, delegation of decision, or group decision.

Decision making in emergency management situation is usually accompanied with stress. Stress is a psychological factor that significantly impacts decision making and that results from a combination of situational factors (e.g. time pressure acting as so-called stressor) and person variables (e.g. available stress coping strategies, see section 2.2.3). Stressful circumstances do not automatically lead to problems in judgement and decision making, but it is a person's active perception that leads to the experience of stress. Stress has a critical impact on decision making and the quality of decisions taken, since it affects perception and focus of attention, information processing capacity and strategies (Kowalski-Trakofler & Vaught, 2003).

4. Applying the psychological framework to develop EMIS

The psychological framework provides a deeper understanding on cognitive processing and decision making in emergencies. This may feed into different areas of work in developing information systems for managing emergencies, as outlined in more detail below.

4.1 Defining EMIS user-requirements

The psychological framework establishes a link to the specification of requirements towards an information system by systematically describing decision tasks in emergency situations. The system should, in general, support the phases of the self-regulated decision making process (forethought, decision, reflection), by providing features that support the actions involved in these different stages or by appropriately changing the user interface in the different process stages. Since person factors play an important role in emergency decisions, a user model should be maintained by the system that stores and updates information on relevant individual variables, like experience or clearance level. In particular, the system should also record and monitor information about users' knowledge and competence. This may be used to identify specific needs for guidance and to provide optimal decision support by adapting the system to individual users in terms of tailoring the information anddata presented and functionalities offered depending on the decision making competence or user group. Appropriate functionality to present different types of information (formal knowledge, context information) should be provided. The presentation of information should enable appropriate use of and interaction with this kind of information. Information presentation needs to take into account general facts about human information processing, like the limited capacity of information processing, which may be further constrained by perception of stress.

4.2 Designing the user interface

The previous section elaborated on the mutual influences of the user interface design and the human perception and human processing. Thus, the design of user interfaces should take into account knowledge of how humans perceive and process information and how they reason and solve decision tasks. Considering the basic mechanisms of human perception and information processing, in general, and situational factors in emergency situations, in particular, which are captured by the psychological framework, guidelines for user interface design can be derived. The design can be leveraged by accommodating top-down processes and related perceptual biases due to experience, context, and goals (Johnson, 2010). Ambiguity in information displays, which would allow different interpretations of the presented information, needs to be avoided. Controls, information, and data displays should rely on existing conventions and common approaches of information displays, and should be consistent (e.g. same position, format). Interface design needs to be based on an understanding of the decision tasks and goals of future users of the system. Considering the fact that the human information processing system and attention is limited and may be further narrowed under stressful conditions, interface design of an information system in particular needs to avoid overload of information presented. Instead, putting information where users are looking or, respectively, guiding attention by creating focal points through salient stimuli (e.g. warning anderror symbols) should be ensured. The Gestalt principles of perceptual organisation provide a useful theoretical basis for deriving basic principles in designing user interfaces (Chang & Nesbitt, 2006; Johnson, 2010). These principles can be translated into design implications on how to structure information displays in order to support users in perceptual organisation and information processing, and to avoid suggesting relationships and grouping between elements that are not intended.

4.3 Applying the framework for EMIS evaluation

The psychological framework can be used to determine relevant variables for evaluating EMIS in terms of its quality and effectiveness for end users. In particular, the user requirements (see section 3.1) and design guidelines (see section 3.2) derived from the framework may serve as reference points against which a system evaluation is carried out. They may be used as a basis for a systematic evaluation (e.g. a checklist approach) of the system features and user interface in terms of the conformance to those requirements and guidelines. In addition, the interaction triangle of user, system, and information (compare Figure 4) serves as a valuable theoretical basis for evaluation. On the interaction axes between these components variables that are meaningful for measurement in evaluation can be identified.

- Evaluation of the user-system axis relates to the subjective **reactions** of users to the system:
- Usability relates to the question whether the communication and interaction between user and system are smooth and whether the system is easy to use and learn. It also includes aspects of the learnability, navigation and complexity of the system.
- User Acceptance addresses the specific question as to whether users consider the research environment and its services acceptable. Commonly, the following user acceptance aspects are distinguished: perceived ease of use, perceived usefulness, and behavioural intention to use (Davis, Bagozzi, & Warshaw, 1989).
- Evaluation of the system-information axis targets the performance in terms of background operations, i.e. the processing, aggregation, and presentation of information through the system:
- Accuracy addresses the question whether system operations on information are accurate and reliable.
- Efficiency refers to the performance in the sense of response time and timeliness.
- Evaluation of the user-information axis addresses information quality and incorporates ideas of the model of information systems success (DeLone & McLean, 1992, 2003).
- Usefulness of information (relevance) relates to the question whether the information and data provided is relevant for the user and his/her tasks, i.e. whether the user's information needs are met.
- Usefulness of format relates to the aspect of information presentation, i.e. the question whether the format in which information is presented by the system is appropriate and meaningful to the user.
- Completeness targets the question whether the information provided is complete for carrying out a certain task. In an emergency management context this particularly means whether information provided is sufficient for emergency decision making.

- Timeliness refers to how up-to-date the information provided is. This aspect is particularly important for context information about the emergency situation (see section 2.3.3), but is in principle also relevant for formal knowledge (e.g. up-to-dateness of emergency plans, see section 2.3.2).

4.4 Implementing training

Training and education are factors that may positively affect decision making in emergencies. Through a careful consideration of the types of knowledge and competence involved in emergency decisions and the explicit definition and structuring of the related skills, as provided by the psychological framework, the learning objectives to be addressed by a training programme can be defined in a systematic and sound manner. This also provides a sound basis for program evaluation measuring whether the training is effective and successful. The knowledge and competence types elaborated in the psychological framework therefore represent a valuable basis for the design, implementation, and assessment of training programmes. The decision making skills elaborated as part of the psychological framework, for example, may be used as a starting point for developing a training of decision making competence for emergency managers (Nussbaumer et al., 2015). By modelling and structuring knowledge and competence in the tradition of Competence-based Knowledge Space Theory (Heller et al., 2006) a systematic selection and sequencing of learning material based on underlying theoretical structures is enabled. Given the current competence state of a learner, meaningful learning paths can be generated to close existing competence gaps and to reach a specified learning goal, taking into account the prerequisites existing between skills. Furthermore, the competence structures and their mapping to training material and assessment problems may serve the implementation of adaptation procedures for personalised learning paths or recommendations of relevant training content and for deploying adaptive assessment procedures.

5. EMIS Design principles

To make the psychological framework tangible for system designers and software developers a set of concrete design principles have been derived from the framework. These design principles may be used as a basis in actual requirements specification, user interface design, and system evaluation for emergency management. The design principles are the means to translate the considerations of the psychological framework into recommendations for designing, developing, and testing an information system. Table 1 presents a total set of 24 design principles. This list of principles is not meant to be complete and may be complemented by additional principles on the basis of further consideration of the psychological framework in the context of a system project.

The design principles can be categorised according to the components of the psychological framework that are aimed to be supported, i.e. the core process (self-regulated decision making) and the person layer aspects (knowledge and competence, other person variables, and perception and information processing).

Table 1: Design principles derived from the psychological framework

Category	ID	Design Principle
Self-regulated decision making	DP.1.01	Support self-regulated decision making cycle.
	DP.1.02	Align user interface design with decision making task.
Knowledge and competence	DP.2.01	Adapt user interface according to the operator's competence.
	DP.2.02	Highlight knowledge type in information visualisation.
Other person variables	DP.3.01	Omit unnecessary information.
	DP.3.02	Link new information to data currently being processed.
	DP.3.03	Use an integrated information format to present an overall picture.
	DP.3.04	Avoid the need for data transformation.
	DP.3.05	Avoid structural interference.
	DP.3.06	Present temporal information.
	DP.3.07	Minimise information dispersal over multiple sources.
	DP.3.08	Adapt information presentation to personal factors.
Perception and information processing	DP.4.01	Be consistent on the visual language for information visualisation.
	DP.4.02	Avoid ambiguity in information presentation.
	DP.4.03	Be clear/strict on focal points.
	DP.4.04	Avoid unwanted focal points.
	DP.4.05	Be clear on figure-ground distinction.
	DP.4.06	Use similar visual attributes for information items that belong together.
	DP.4.07	Locate information items that belong together close to each other.
	DP.4.08	Arrange elements on the interface in a balanced, symmetric manner.

Category	ID	Design Principle
	DP.4.09	Apply simplicity and conciseness.
	DP.4.10	Use visualisations to give an overview of data.
	DP.4.11	Make use of affordances in interface elements.
	DP.4.12	Use multimodal visual displays

The principles given in Table 1 constitute higher-level advice for design decisions and may be translated into requirements and concrete ideas on features and functionality of an information system in an emergency management context, and the design of the interface and information visualisations within such system. The design principles may furthermore be used as a checklist for reviewing and evaluating existing information systems.

These design principles have been further elaborated and specified following the design actions schema described by Spence (2011), providing for each principle a general description, ideas how the principle can be implemented in system design and development and examples of implementation, an explicit link to the psychological framework (and related background literature), as well as criteria detailing how the principle can be evaluated. An example is shown in Table 2.

Table 2: Example of a detailed design principle specification

DP.3.04	Avoid the need for data transformation
Description	Displays and information should be designed in a way that the operator does not need to perform data transformation (e.g. mixture of meters and kilometers in the user interface). Information and instructions should be provided in a most direct way.
Solution Approach and Examples	Information should be presented in the way users think, are trained and are used to. For example, if they know that flood levels a critical above a level of XX centimetres, then the flood level should be presented in cm and not in meters or inches. Furthermore, no different types of measures or scales should be used to avoid confusion or misinterpretation. For all types of information it has to be checked how the users are used to deal with, so that the respective data can be presented consistently in a way that they do not have to do data conversion.
Theory	Human information processing capacity is limited (Goldstein, 2010). High stress conditions, as usually given in emergency situations, lead to further reduced information processing capacity and inhibition of new information sources (e.g. St.Pierre et al., 2008). Cognitive functions are hindered under stress (Hancock & Szalma, 2003), which may compromise the conscious recognition of new or different measures or scales and the need for data conversion. Consistent and familiar ways of presenting data reduce cognitive load.
Evaluation Criteria	Analysis of how information is displayed and whether it has to be transformed by the operator to make use of it. Investigation of cognitive load when presenting users with information.

To better illustrate how the design principles may guide design and development of system functionalities and user interface, two paper prototype examples of a decision support system for emergency management and the incorporated design principles are presented below.

The application screen of both prototypes (see Figure 5 and Figure 6) is organised into four parts (DP.4.06, DP.4.07, DP.4.08): On the bottom of each page there is the bar with coloured buttons to open the different modules of the system (DP.4.11). On top of each page there is an information bar, where status information is rendered and updated. The information bar shows general information related not only to a specific module, i.e. information about the active user, the time (DP.3.06). In addition, guidance and advice (DP.2.01) from an emergency management tutor are given. The centre and focal area of each page is dedicated to the modules (DP.4.03), so that the active module renders its content there. Each individual module places control buttons on the left side, in order to have a consistent layout (DP.4.01). Consistent layouts are necessary to avoid information dispersal, which can overburden a stressed operator (DP.3.07).

The start screen (see Figure 5) shows the welcome information consisting of two parts, a diagram explaining the self-regulated decision making workflow to follow (DP.1.01, DP.4.10) and information about the current incident. Each of the phases of decision making is highlighted with its own colour (DP.4.06, DP.4.05), including the communication and collaboration tools depicted in the centre of the diagram (DP.4.03). The phases of the self-regulated decision making approach are also reflected in the modules bar, where the buttons are grouped according to these phases (DP.1.01). The grouping is done by putting the buttons related to the same phases closer to each other (DP.4.07) and by rendering them in the same colour (DP.4.06). On the right side of the content page information about the current incident is given (DP.4.07). If no incident is active, the information

provided on the screen is limited to general information (DP.3.01). After creating or joining an incident, the emergency management tutor may give advice on recommended actions (DP.2.02), e.g. to start with information gathering by using the respective modules accessible through the blue buttons in the button bar (DP.1.01; DP.1.02).

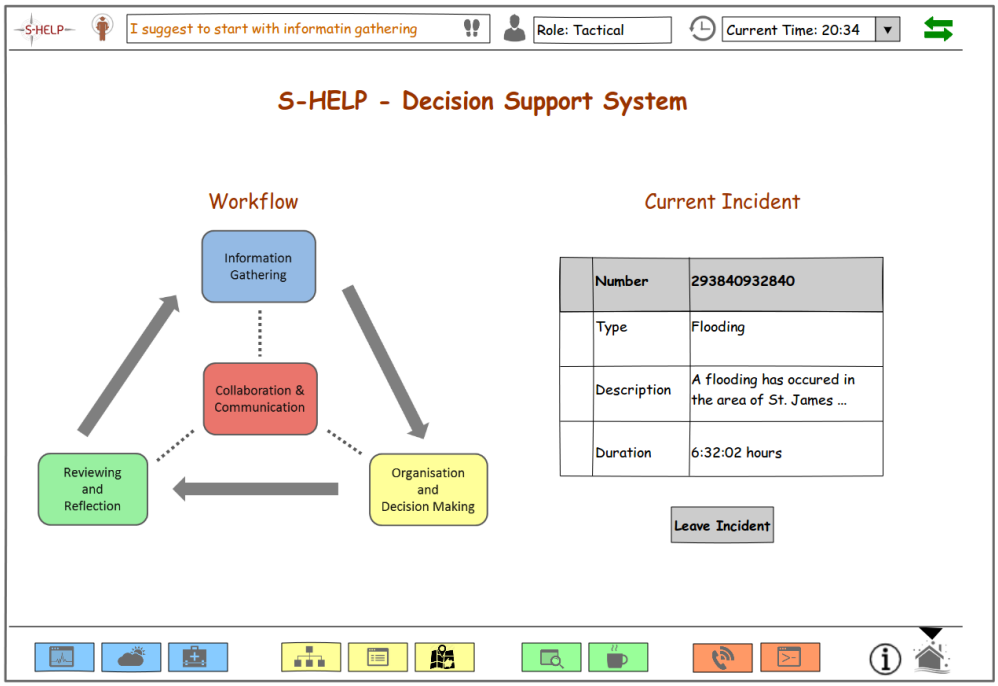

Figure 5: Paper prototype of the start screen of a decision support system for emergency management

A resource module (see Figure 6) may provide access to information about the currently available resources (DP.1.02, DP.3.03). It depicts different types of resources on a map and also gives details on demand in a table on the right side. A consistent set of icons is used to refer to the several resource types (DP.4.01). Additionally, blue and red circles are surrounding the resource symbols (DP.4.12). A red circle indicates that the resource is not available any more or not accessible. A blue circle means that the resource is available, whereby the thickness indicates how many items of this resource is available (DP.3.04).

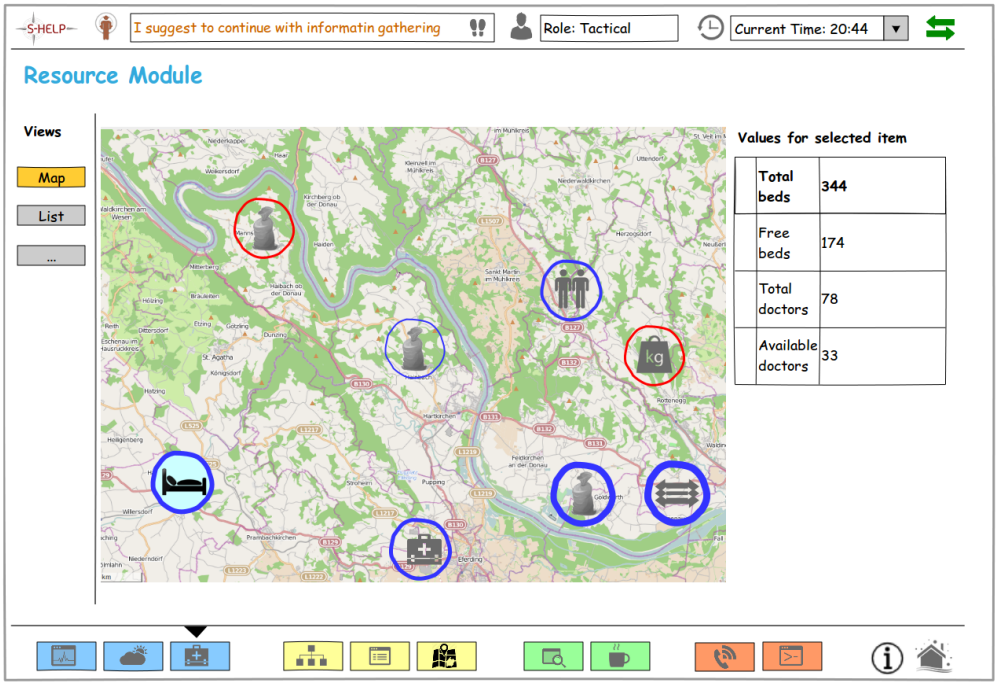

Figure 6: Paper prototype of the resource module of a decision support system for emergency management

6. Conclusion

In this paper we have introduced a psychological framework that models decision making in emergency management by integrating different areas of psychological research. The framework enriches the knowledge base on emergency decision making in the context of information system research by introducing a psychological perspective and providing a deeper understanding of the cognitive processing and decision making of people involved in emergency response at strategic, tactical, as well as operational level. Our approach to modelling decision making provides an explanatory framework of the decision making process by presenting it as a multi-step procedure and elaborating on involved processes of perception, involved knowledge and information, and influencing factors in emergency decisions. The framework complements existing outcome-oriented theories modelling and predicting human decision making, which are traditionally incorporated in the data model and decision context of decision support systems. It has been elaborated and illustrated how the psychological knowledge of the framework provides guidance for requirements specification on EMIS features and for user interface design of information systems, as well as for system evaluation. In addition, the psychological framework may be used as a basis for developing training concepts and programmes for decision makers in emergencies. Design principles and example paper prototypes of a decision support system for managing emergencies have been presented to illustrate how the psychological framework can be translated into system design.

Ongoing work consists of leveraging the psychological framework by applying it in the development of a comprehensive decision support system that will provide a novel approach to emergency management. Furthermore, the framework serves as a basis for systematic psychological experimental studies on the influence of, impact on, and interrelation between different variables in emergency decision making (e.g. examining the effect of user interface design and/or stress perception on decision performance), with the aim of further investigating how to optimally support cognitive processing in managing emergencies. A first study has been carried out to analyse the effect of implementing selected design principles based on Gestalt theory in visual displays on subjective feedback and decision task performance in an emergency management scenario. Further studies will be conducted on other design principles and on variants of concrete interaction elements or modules in a decision support system.

The psychological framework derived in this study, has potential for reuse beyond an emergency management context. The generic components of the framework apply to different types of decision situations e.g. in business management). While the core process of self-regulated decision making remains the same in diverse use cases, the specific psychological factors and knowledge and competence areas are different and have to be elaborated for the respective field of application.

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