Helene Degerman[1]
Staffan Bram[1]

Modelling of response to emergencies with cascading effects

Deliverable Number:	D3.1 v2
Date	April 15, 2016
Due Date (according to DoW)	June 30, 2015
Dissemination level	PU

Grant Agreement No:	607665
Coordinator:	Anders Lönnermark at SP Sveriges Tekniska Forskningsinstitut (SP Technical Research Institute of Sweden)
Project acronym:	CascEff
Project title:	Modelling of dependencies and cascading effects for emergency management in crisis situations

[1] SP Technical Research Institute of Sweden (SP)

Table of Content

Executive Summary

This report is based on the decision-making theories presented in CascEff D3.2 "*Decision-making and human behavior in emergencies with cascading effects*". In this report decision-making in emergency response is further exemplified by models.

First, the analytical baseline, emergency response as a joint cognitive system, is presented and visualized. In a joint system the performance is determined by the combined performance of human agents and artefacts. Artefacts could be latent preconditions, like regulations and infrastructure or more directly involved in shape of a procedure or technical device. In an emergency the context is crucial, and the context is characterized by emergence (cascading effects), time constraints, uncertainty, wickedness and high level of damage.

The main factor in emergency response is the human team cognitive processing, and examples of such functions are identifying problems, sense-making, re-planning (triggered by change), evaluation, decision-making and coordination. These functions are hard to observe and are describes as processes rather than points.

In the modelling theory chapter five systemic models are presented, all of them recognize cognitive functions like decision-making as feedback and feedforward processes. These parallel processes create a local understanding and locally rational actions. When several different agents collaborate it is important to create a common ground. The creation of a common ground is however also a process, not an appeal or anything which could be demanded by someone else, as through a procedure or checklist. Coordination and collaboration are also cognitive functions that must be supported for being able to achieve goals.

In the report findings from CascEff D3.2 and the modelling theory chapter in this report influenced a visualization of emergency response in flowcharts. The flowcharts are found in Appendix A. Central findings are a gap between real emergency work and the image of it from the outside. The response operations are often viewed as sequential, rehearsed and simple actions. This in contrast to how both modeling theory and the actual modelling and visualization imply.

It is concluded that the modelling of emergency response decision-making should be a beginning for design work of the Incident Evolution Tool. A generic design process is suggested, a process that presupposes the need for an iterative design course, aimed for a better match against real work success factors and limitations.

The result of the work summarized in this report indicates some risks coupled to poorly designed artefacts, and finally the importance in designing and properly informing decision support tools is emphasized. A poorly designed tool could steal cognitive capacity from the rescue team, leading to a potential fail in understanding the emergency situation, resulting in an additional fail in managing and controlling the emerging cascading effects.

1 Introduction

The focus in this report is modelling of decision-making and other macro-cognitive functions in emergency response.

The report is largely based on the contents of CascEff report 3.2 "*Decision-making and human behavior in emergencies with cascading effects*". In this report the theories of general decision-making presented in D3.2 is further exemplified in methods/models. An emergency response situation is visualized in flowcharts (found in Appendix A).

1.1 Emergency response as a joint cognitive system

In this report an emergency response situation is viewed as a joint cognitive system, highly dependent on the context that is characterized by emergence, or *cascading effects*. This analytical baseline is further introduced in this section.

In a socio-technical system agents as humans, technology, organization, context and regulatory preconditions on different societal levels, are seen as a whole. The system is ***joint***. The joint system is greater than the sum of its parts. The focus in a joint system is coagency, dynamic interactions and flows between agents. In a joint system *risk occurs in interactions between agents*, not within the agents themselves (Hollnagel & Woods, 2005). Therefore, these system aspects must be a prerequisite when designing system artefacts, for example decision support (Potter, Woods, Roth, Fowlkes, & Hoffman, 2006).

The environment and **context** is crucial for a joint system's performance. The context affects how situations are evaluated and how decisions are made. It requires more than a simple action for the system to perform. Decision making is a process, not that much a discrete point "that is made" (Patterson & Hoffman, 2012). In CascEff a critical emergency environment is added to the joint context-dependent societal system. The emergency situation contains a high level of surprise, time and resource constraints and often severe consequences. The emergency situation is **emergent** and cascading effects, complex non-predictable and non-proportional outcomes, are somewhat expected.

In an emergency response situation, the rescue team and other actors involved have to achieve the not so easily observable goals; sense-making, problem detection, planning and re-planning, deciding, coordination, analyzing, judging and of course action. Performing such macro-cognitive work makes the system **cognitive**.

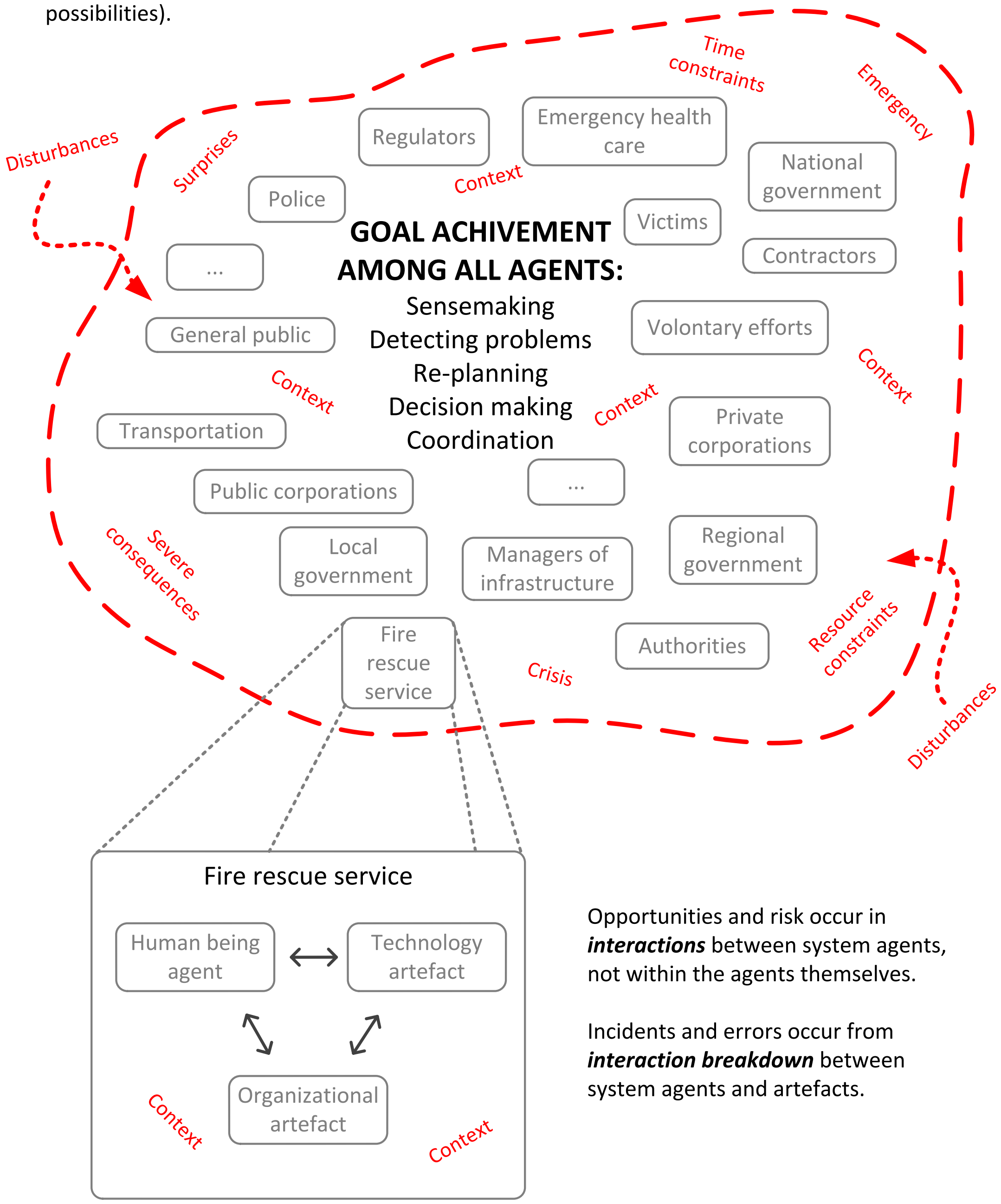
See Figure 1 for an introductory visualization.

A joint cognitive system in emergency response

A joint system consists of several **agents** (on different abstraction levels) and **artefacts** (between or within agents). These co-exist, some have a long-term latent influence on an emergency and some have direct influence and faster feedback and feedforward loops.

The system's combined ***overall performance*** is of interest, not performance of an isolated agent.

System ***performance depends on the specific context*** and environmental constraints (and possibilities).



Opportunities and risk occur in ***interactions*** between system agents, not within the agents themselves.

Incidents and errors occur from ***interaction breakdown*** between system agents and artefacts.

Figure 1 Visualization of a joint cognitive system in emergency response. Further explanations is found in the description of the flowcharts in chapter 4.

2 Modelling theory

CascEff D3.2 “*Decision-making and human behavior in emergencies with cascading effects*” describes a number of different cognitive and social functions and properties that are either components of decision-making or that relate to it in some way. In the literature, decision making is normally examined together with activities such as problem detection, sense-making and situation assessment, coordination, planning, adaptation and re-planning, without necessarily imposing some sort of hierarchy (Endsley, Hoffman, Kaber, & Roth, 2007).

Patterson and Hoffman (2012) have developed a framework for macro-cognitive functions, which are continuous and always overlap. Decision making is occurring in relation to all of the other functions, see Figure 2 below.

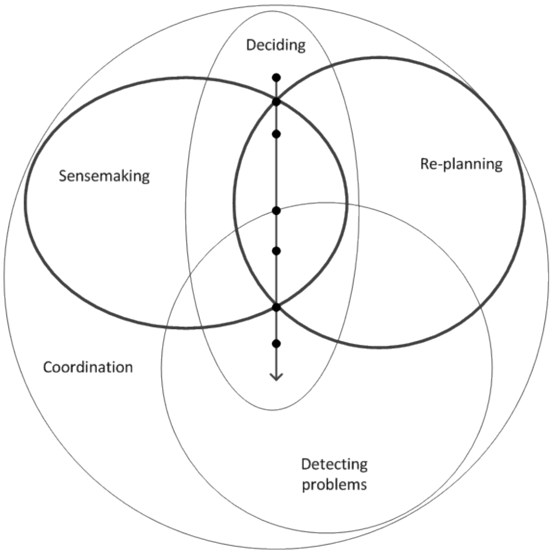


Figure 2 Visualization of Patterson's and Hoffman's (2012) framework of macro-cognitive functions

Studies where decision making is modeled usually include this as one activity in a network of other attributes and resources. Functions like these form the base of actual strategical and operational decisions such as location of the command post, managing communications and logs, reconnaissance, preparing goals and plans, initiating rescue operations and assessing resources (Nja & Rake, 2009).

The use of models that capture the interactions and relations between system agents and artifacts is essential for understanding emergency response performance and decision making (Salmon et al., 2014). In this kind of work it is important to use a systemic point of departure that reflects real work challenges, and the non-observable and non-linear aspects of a socio-technical emergency response system (see for example Abrahamsson, Hassel, & Tehler, 2010; Chen, Chen, & Li, 2012; Norros et al., 2009; Salmon et al., 2014; Stanton & Bessell, 2014).

This chapter will begin with an overview over the field of work modelling, followed by a few examples of studies where decision making in the field has been modeled. These models will be used as an inspiration for important activities or features of emergency response decision making and has also inspired the modelling and visualization task of D3.1.

2.1 Ingredients in the modelling of macro-cognitive functions

Safety critical complex systems are characterized by emergent non-linear flows and interactions. In a complex system, input and outcome are not necessarily proportional. Outcomes and effects may be unexpected. Therefore, a hierarchical cause-effect relationship is not always applicable when modelling safety critical socio-technical systems. Despite this, it is quite common to attempt to model decision-making in a simple linear way (Kontogiannis, 2012).

When modelling decision-making in an emergency situation it is central attempting to understand cognitive, operational and collaborative demands on-site (Norros et al., 2009). A systemic approach includes complexity and takes consideration to expert intuition, a key ingredient in distributed team decision-making (Kontogiannis, 2012). Wilson (2014) has identified six aspects that characterize the system perspective. Each model claiming to embrace a system approach should represent the following:

- **Systems focus** - Include the whole socio-technical system and recognize aspects of complex interactions and flows within the system.
- **Context** - Accept and manifest the difference between laboratory studies and contextualized work in a real setting. Analysis of real decision-making and other macro-cognitive aspects must be conducted *in the wild* (Hutchins, 1995).
- **Interactions** - The model must capture that interactions are complex and not linear. Focus must be the interactions themselves, not the things interacting.
- **Holism** - The cognitive, physical and social system must be combined, because a system is not easily split into clear and divided pieces.
- **Emergence** - A system in real life situations will not perform predictively, this is normal and expected. Emergent properties of the system must be recognized throughout the life-cycle.
- **Embedding** - The system analysis work must be embedded in practice and be a key ingredient in all development.

Woods and Roth (1988) identified features important for cognitive engineering and cognitive design. Despite the importance of assuming complexity and interactions in a real world context, just like stated in the bullet list above, they argued for some vital features when analyzing cognitive demands for system design:

- Complex interactions and flows must be a prerequisite. In this way the human being gets a chance of managing and co-existing with complexity, instead of being forced to interact with poorly designed technology, originated from an oversimplification of the reality.
- The analyst must assume that human beings' strategies for problem-solving are logical and rational in its context, not trying to adapt observable human behavior to an otherwise "ideal" system.
- Knowledge utilization is not simple and predictable. Just because a human knows something, it does not mean that the knowledge will be activated in every useful situation. Training, procedures and technology must match knowledge being context dependent.

- Design and development should be principle- and problem-driven, not technology driven. First, the problem-solving in the system as a whole must be understood and then different solutions, maybe technological, can be evaluated.
- A tool cannot be evaluated on its own. The system's combined overall performance is of interest, not performance of an isolated technology agent.

2.2 Examples of modelling techniques

There have been several attempts to develop support for emergency response teams. One reason for many of these failing is a lack of understanding of real-world problem-solving and absence of involvement of end users in the process (Norros et al., 2009). To bridge the gap between reality and technology based on a mismatching component failure paradigm model, researchers have tried to address emergency response through systemic methods and approaches.

This chapter presents general decision-making and cognitive functions analysis models that could be applied to emergency response.

2.2.1 Cognitive Task Analysis (CTA)

CTA is an umbrella term for a family of methods with the same systemic approach and purpose for understanding real-work and real knowledge. Modern CTA was born as a reaction against cognitive psychology and laboratory experiments. These results were considered too limited for direct translation into a real world context (Militello & Hoffman, 2008).

CTA methods are used for informing design of technology interaction, organizations, training and other socio-technical system components. The analysis model includes human beings, technologies, working environment and context. The purpose of CTA is to analyze not only the visible and observable individual and group human behavior, but rather the underlying aspects that influence and affect experts in complex performance. The cognitive process behind a certain action gives meaning to the action itself. The analysis elicits mental processes behind human behavior, for example information processing, judgement, diagnosing problems, decision-making and action (Crandall, Klein, & Hoffman, 2006).

A generic CTA consists of three main steps (Crandall et al., 2006):

- **Knowledge elicitation** - methods used to gain information about judgement, strategies, knowledge and skills that underlie performance. Data is collected through for example interviews, observations or operators' self-report.
- **Data analysis** - structuring data, identifying findings and creating a meaning.
- **Knowledge representation** - displaying, presenting and communicating findings and meaning

A generic analysis structure is presented in Table 1. Specific CTA-method is chosen depending on the purpose of the analysis, the question being asked, the domain and context. CTA requires skilled analysts, especially since it takes quite some time performing the analysis. (Zachary, Hoffman, Crandall, Miller, & Nemeth, 2012).

Table 1 A generic cognitive task analysis structure, adapted from Zachary et al (2012)

Task	Activities and output
Establish purpose and define product/expected outcome	Specification of expected scope of the analysis and the macro-cognitive functions being analyzed, the format of results and the criteria for establish completeness.
Describe work domain and context	All CTA methods require reference to domain specific cases which are linked to problems and performance.
Segment cognitive components and interrelationships	Data collection. Interviews and/or observation of real or simulated work, identifying "chunks" of knowledge involved in work. Declarative, procedural, perceptual and motor skill knowledge is segmented. Identify how the segments affect work performance.
Description of internal structure of each knowledge component and relationships of work processes	More focused interviews and/or observations. Analyze and describe attributes of each knowledge chunk from the previous step. Identify context cues or associations that activate or affect the use of each chunk.
Create representation of result	Translate detailed descriptions into a suitable representation language. Verification test for ensuring representation is valid and complete (given criteria in first stage)

2.2.2 Cognitive Work Analysis (CWA)

CWA, inspired of Rasmussen's (1986) work, is a framework for analyzing socio-technical systems and has strong links to Cognitive Task Analysis. The aim of modelling work in CWA is to design robust, efficient and safe work structures, with an adequate way of aiding and constraining work in the right way and in the right place. CWA was born after the Three Mile Island nuclear incident and is, just like CTA, a reaction to well-defined stepwise procedures within safety critical work. The purpose of CWA is making real-world capabilities and constraints visible to operators, for increasing chances of well-informed decisions being made (Militello & Hoffman, 2008). The idea is that design must support (and encourage) adaptive human activity, not on the contrary, training operators to understand and adapt to (sometimes poorly designed) technology. The purpose is to identify the constraints that shape work, not that much predict the work itself.

Sanderson, Naikar, Lintern, & Goss (1999) has drawn a graphic picture of the ingredients in human adaptive activity, see Figure 3. First, the circle is divided in **activities** (what, why, with what and how) and **agents** (who and with whom). Second, the circle consists of four types of cognitive abilities and constraint that need to be considered in real work analysis. These are; (a) the ones related to **individual** tasks, micro-cognition and individual competence and cognitive assignments, (b) the ones related to the **group**, collaboration and coordination, (c) the **work structure** and work domain and finally (d) aspects regarding **cognitive processing** (data processing) and strategies for travelling between cognitive stages (knowledge stages).

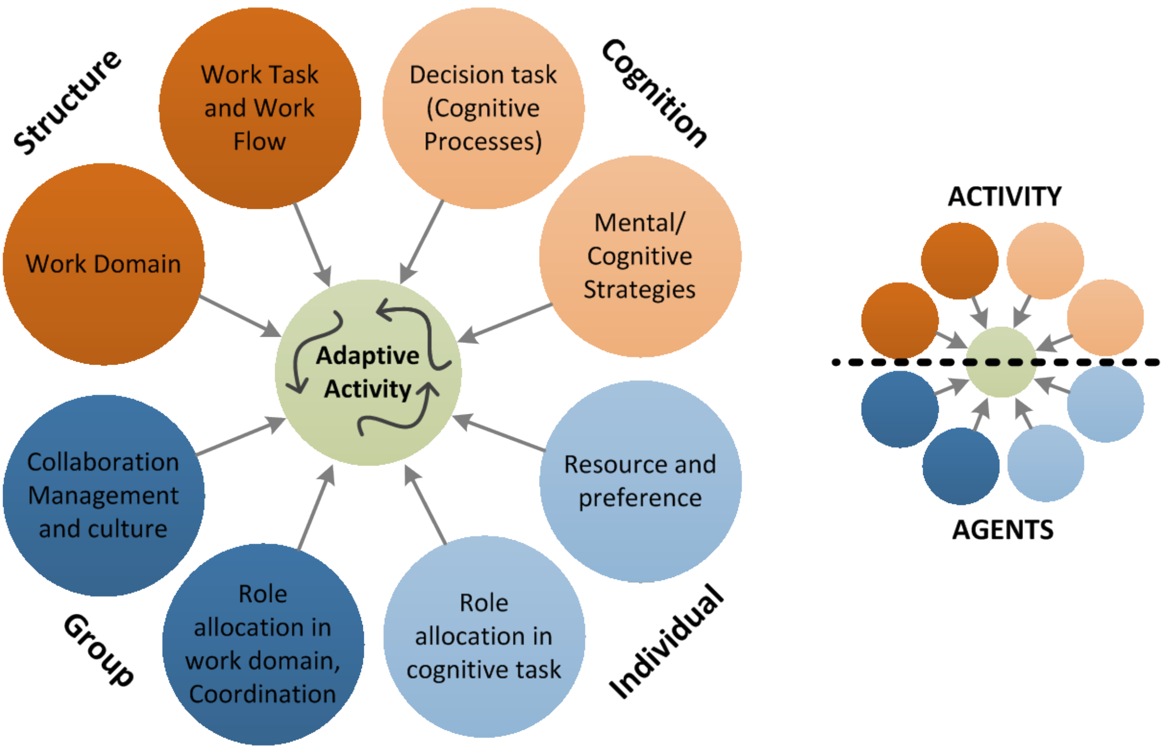


Figure 3 Aspects that affect and influence human adaptive activity in socio-technical systems (Sanderson et al., 1999)

In CWA the human adaptive activity aspects are summarized into five analysis phases as follows (McIlroy & Stanton, 2011);

Work Domain Analysis - The first step is to identify basic constraints of the work system and create an abstraction hierarchy. At the highest level of abstraction the systems' functional purpose is found, at the lowest level the physical objects.

Control Task Analysis - The analysis step identifies activities on a general level within the system, the activities are not yet coupled with a certain responsible role. This highlights links between functional fulfillments in a certain situation and could inform the system design.

Decision Ladder - is a part of the Control Task Analysis and identifies activity in decision making specifically. The diagram is visualized in a seemingly linear manner, se Figure 3, but it is expected for decision makers to travel in a complex way through the ladder. The way through the ladder differs especially between beginners and experts. *Shunts* take the decision maker between stages of data processing (cognitive processes) and *leaps* between two stages of knowledge (cognitive stages). The rectangular nodes represent data collection, the circular nodes represent the state of knowledge following the data collection and processing.

Strategies Analysis - The third phase of CWA analyzes how the identified activities from step two are to be performed in different ways. Both human and non-human agents can perform tasks.

Social Organization and Cooperation Analysis - The SOCA phase analyzes organizational structure and constraints and looks at cooperation between actors. The analysis could result in a more effective allocation of functions (for example between human and technology in a specific organizational context).

Worker Competencies Analysis – This step analyzes the required competences within the system. The analysis step can be performed with different aspects in mind (or with just a few aspects if that is applicable to the certain case). Aspects could be Skill-based behavior, Rule-based behavior or Knowledge-based behavior. There are also aspects and methods connected to findings in the decision ladder specifically.

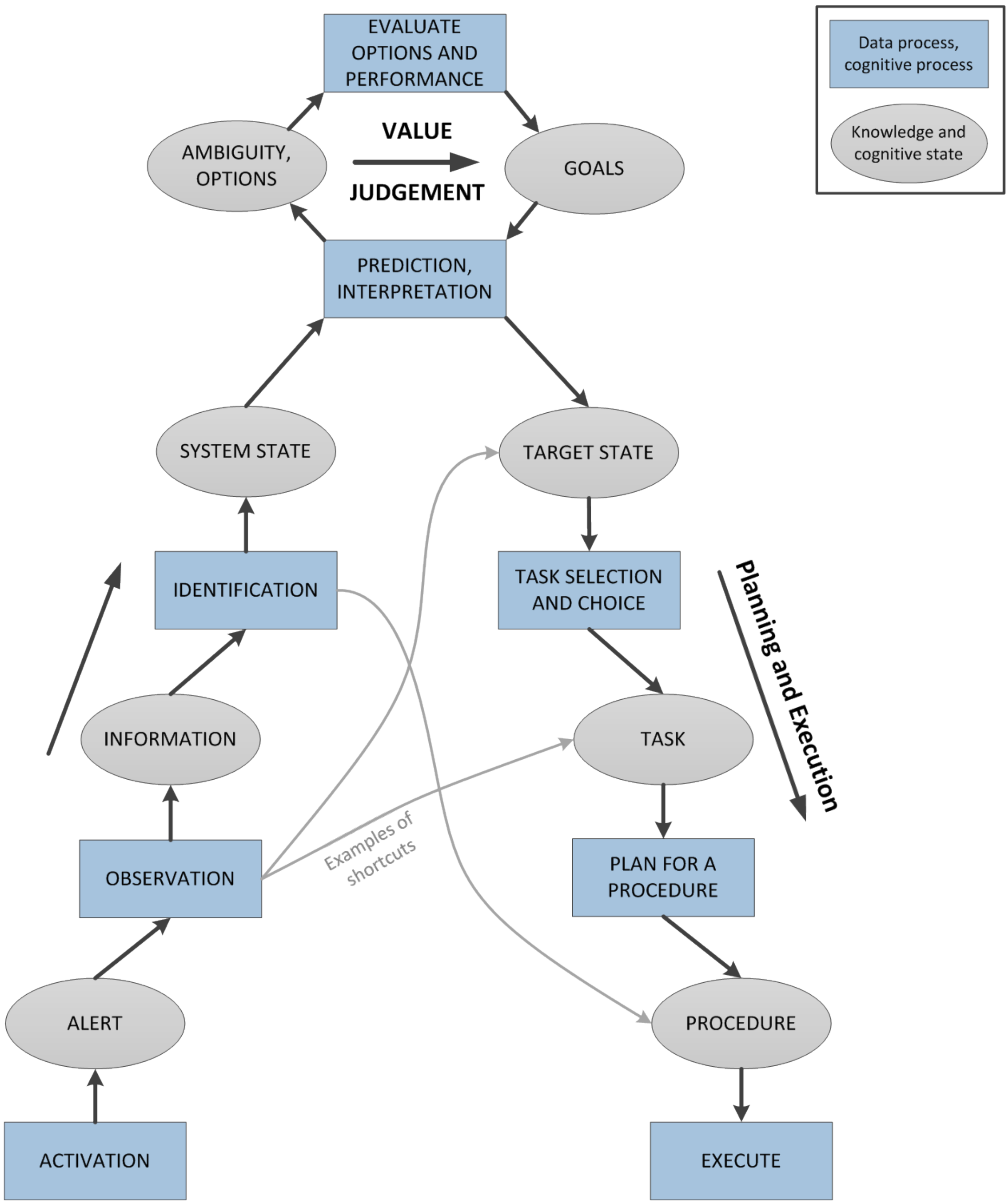


Figure 4 Decision ladder, adapted from Rasmussen (1986)

There have been attempts to update and modernize the decision ladder, since much has happened in in the past decades regarding the understanding of distributed cognition and decision making. Lintern (2010) argues that an evaluation function is embedded in planning and execution and that a rational evaluation and comparison of options is not realistic. Therefore he has modified the decision ladder and changed the nodes for a better match with naturalistic decision making and cognition. For example “execution” is changed to “execute and coordinate actions", "task" is changed to "understand what must be done" and the planning for a procedure is extended with a process of valuing how the plan achieves goals.

2.2.3 Contextual Control Model (COCOM)

The Contextual Control Model describes system performance and the decision-making process from four control modes (Hollnagel, 1993). The model recognizes interactions in a joint system being of greater importance than the separate system parts (Hollnagel & Woods, 2005). In the model the details of human cognitive processing *in the mind* is replaced by a functional approach, inspired by Neisser's (1976) perceptual circle and Hutchins (Hutchins, 1995) contribution of distributed cognition in the wild.

The four control modes are "Scrambled", "Opportunistic", "Tactical" and "Strategic" and each control mode refers to a changed level of control and has its own characteristics, see Table 2 below. The different control nodes are context specific, and travelling between them are both natural and expected. No mode is in fact better than another, but a higher control mode (strategic) means more control and a lower (scrambled) means low or no control (Palmqvist, Bergström, & Henriqson, 2012).

Table 2 Characteristics of the four control modes (Palmqvist et al., 2012), originally adapted from (Hollnagel & Woods, 2005).

Control mode	Number of goals	Subjectively available time	Evaluation of outcome	Selection of action
Strategic	Several	Abundant	Elaborate	Based on models/prediction
Tactical	Several (limited)	Adequate	Detailed	Based on plans/experience
Opportunistic	One or two competing	Just adequate	Concrete	Based on habit/association
Scramled	One – not necessarily task relevant	Inadequate	Rudimentary	Random

COCOM is visualized through a cyclical process, where the current understanding of the situation is an essential part and always changing. Visualizing the iteration and development of an adaptive understanding is a crucial component when embracing the macro-cognitive and naturalistic approach to decision making. The iterations and current actions are built upon previous actions, and a continuous process of feedback and feedforward influence and affect the understanding of the situation (Bye, Hollnagel, & Brendeford, 2000).
Time is an important and crucial resource for determining the control mode. Time is a parameter often recognized merely as a sequencing condition in linear decision making models. In Figure 4 below the human action cycle, that COCOM is built upon, is presented. In the circle the **goal-directed action** (the goals vary between identification, diagnose, evaluation and action) provides new **information** about the situation, which affect and modifies **understanding** of the situation, which in turn forms the basis for a new goal-directed action. The cycle describes the dynamic relationship between individual and team understanding, action, feedback from and feedforward to the contextual situation.

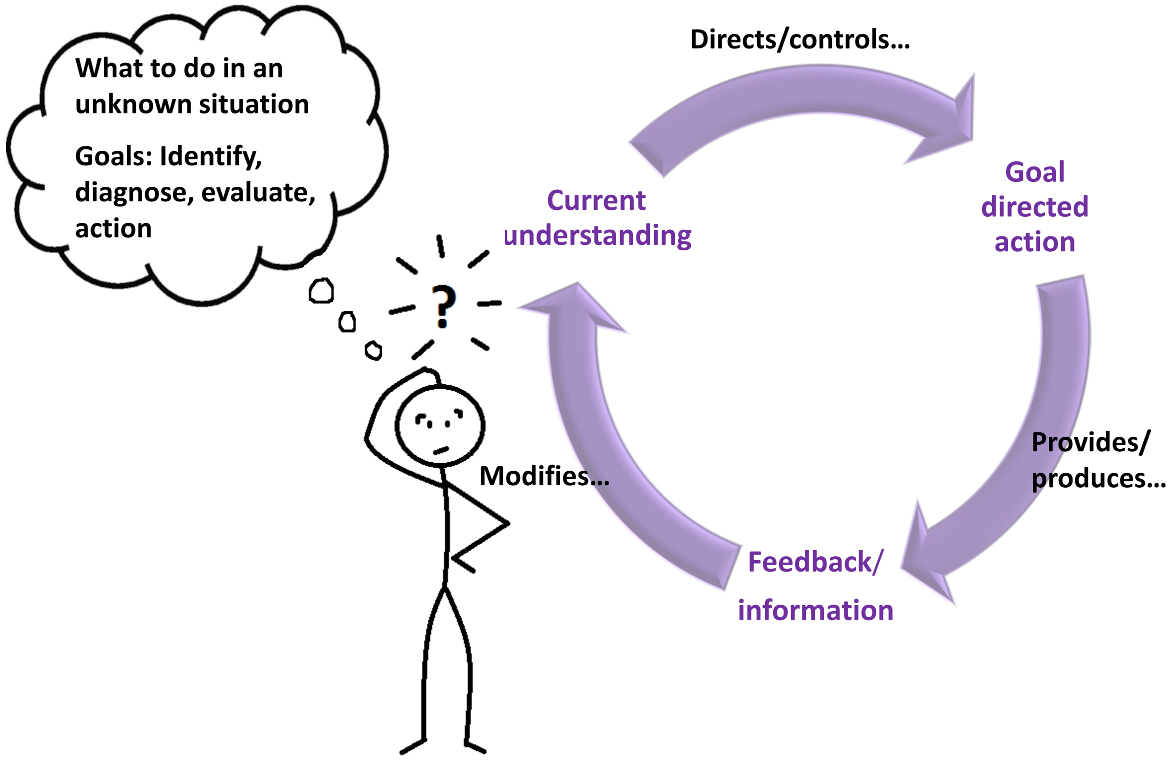


Figure 5 Human action cycle (Bye et al., 2000) based on the principles of Neisser's perceptual cycle (1976).

2.2.4 Accimap and Actormap

When analyzing emergency decision making, it is also possible to use a pure accident analysis method (unlike the previous models, which deals with decision making independent the situation). There are several such methods (e.g. STAMP (Leveson, 2004), Risk Management Framework (Jens Rasmussen, 1997) and AcciMap (I Svedung & Rasmussen, 2002)) that match the emergent socio-technical systems in an efficient way.

Rasmussen and Svedung (2000) has developed the *Accimap(/Actormap)* model. The model could be applied on an escalating emergency situation, or proactively or reactively for learning. The model assumes that decisions are not "distinctive points". Instead decision making is part of a social context and value system on six different levels in society (government policy and budgeting, regulatory bodies and associations, local area government planning and budgeting (typically company management), technical and operational management, physical processes and actor activities, equipment and surroundings) (Jens Rasmussen, 1997), see Figure 5 below.

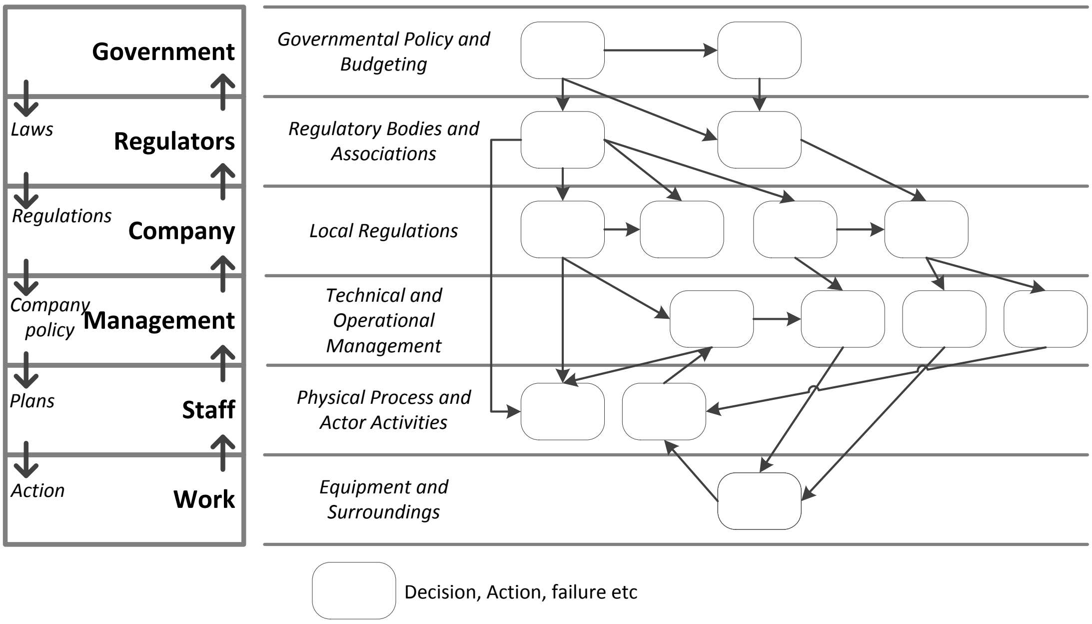


Figure 6 Rasmussen's risk management framework and an Accimap (Salmon, Cornelissen, & Trotter, 2012)

The model also involves environmental stressors and is a cross-disciplinary way to include aspects from more than one research and practice field. The Accimap model gives an opportunity for understanding decision makers on all levels of society, in their respectively context. The focus of the analysis is control of hazards at the bottom of the socio-technical system. Here the systemic approach differs from other accident analysis methods, which typically concentrate on a specific societal level or a defined organization or actor. The Accimap is generic and can be applied to any emergency type (Salmon et al., 2014).

When analyzing accidents and risks a cause-consequence chart is complemented with a specific *Accimap*. The decision-makers, planners and actors involved, in all levels of society, who may have been involved in creating the conditions for an accident, are identified. After that, the Accimap is generalized, a *generic Accimap* is created. The group identities are then further analyzed in an *Actormap*. The Actormap identifies decision making nodes that should be interviewed and analyzed in further studies of normal work. An *Infomap* could show communication links between actors and nodes (Inge Svedung & Rasmussen, 2000).

2.2.5 An integrated model of decision making and incident command

In Belgium, a model integrating decision making and incident command has recently been developed.

Regulations do not impose a decision making model for response. Every service in Belgium more or less developed its own practices. In training courses, the relatively simple so-called BOB[1]-model is teached, which can be considered as a common basis for decision making for all Belgian fire services. The same model is used in the Netherlands.

[1] BOB stands for 'Beeldvorming – Oordeelsvorming – Besluitvorming' and corresponds in English to Representation by data collection – Judgement based on Analysis – Decision

A distinction is made between the decision making model and an incident command model, since decision-making not being the final goal of incident management. The 3 main steps of decision making are extended with 2 complementary steps:

1. **Analyze** the situation by collection information on (1) what is needed, (2) what is available. This includes an exploration of the scene and its environment. See Figure 9.
2. **Assess** the situation: based on the collected information, the Incident Commander (IC) will make a preliminary decision and plan of action. IC will check whether the information was complete/sufficient. If not, the IC will seek for additional information before finalizing the plan of action.
3. The next step is the **Decision** on a plan of action, clearly indicating what actions and measures need to be taken, including the adequate resources
4. The fourth step, **Command**, refers to the orders given by the Incident Commander to execute these measures and actions.
5. The last step involves **Leadership and Control** and refers to the continuous monitoring of the Incident Commander of the evolution of the situation, the appropriateness of the IC's decisions, efficiency of the actions and measures etc.

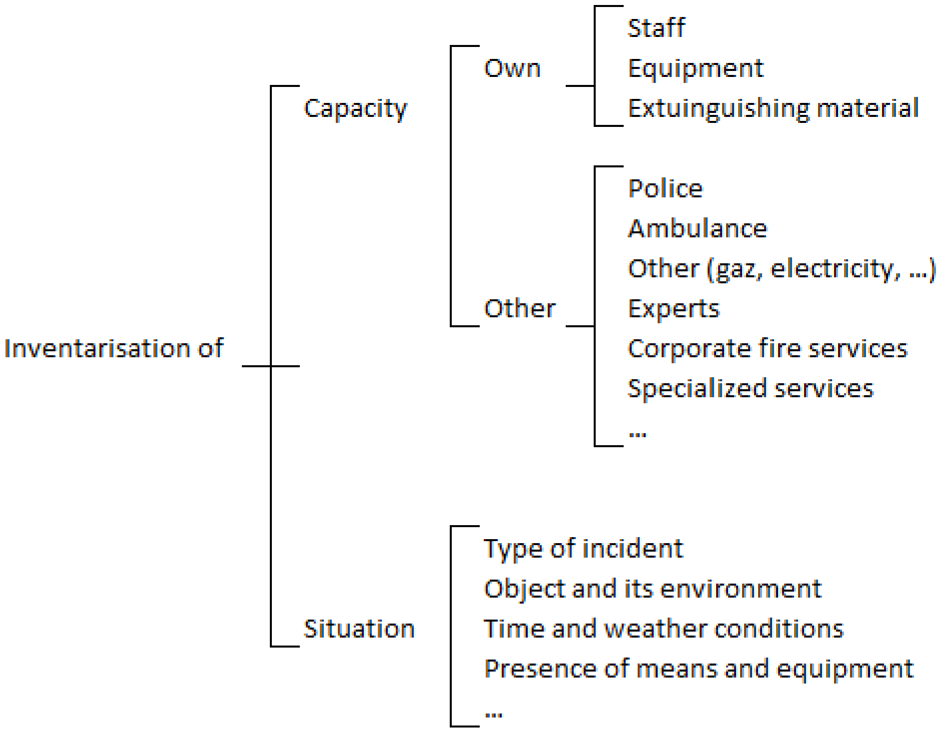


Figure 7 Representation of the first step, Analysis (Oefenbank Nederland)

All the steps follow a chronologic sequence and should be performed continuously as a loop, the first 3 steps are a decision making process, the last 2 steps are a part of the incident command (& control) process, see Figure 10.

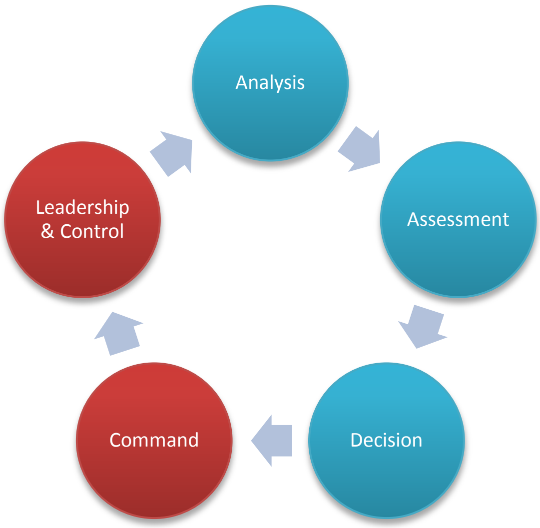


Figure 8 Decision-making and command and control loop

For more complex incidents, with multi agency coordinator, a specific, more elaborated decision making model has recently been developed.
Based on a comparative analysis, the model integrates strong and weak points from different models, of which the most important are: the previously mentioned BOB model of the fire services, the Cybernetic model and the (D)OODA loop.

Basic models, such as BOB, limit the key activities to Representation → Analysis/judgement → Decision

The cybernetic model, a more advanced model, distinghuises the following steps: Data collection → Analysis → Decision → Dissemination

See Figure 11 for a comparison.

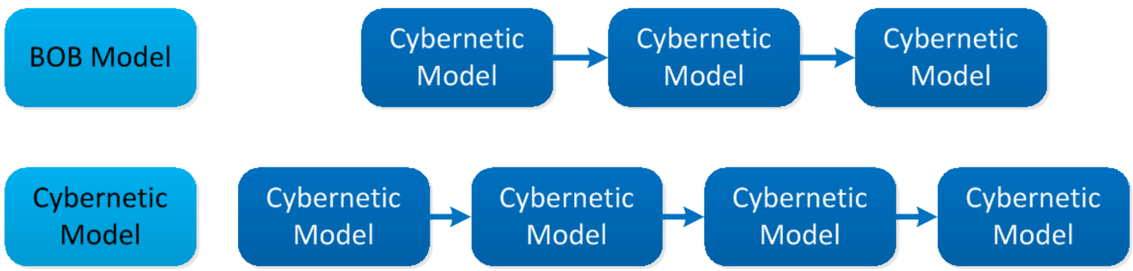


Figure 9 BOB model and Cybernetic Model

Based on a comparative analysis, a new, generic model was developed as good practice, the so-called IBOBBO[2] model (because of the abbreviation in Dutch of the consecutive steps). It integrates relevant aspects from the above-mentioned models.

[2] Informatiegaring - Beeldvorming - Oordeelvorming - Besluitvorming - Bevelvoering - Opvolging

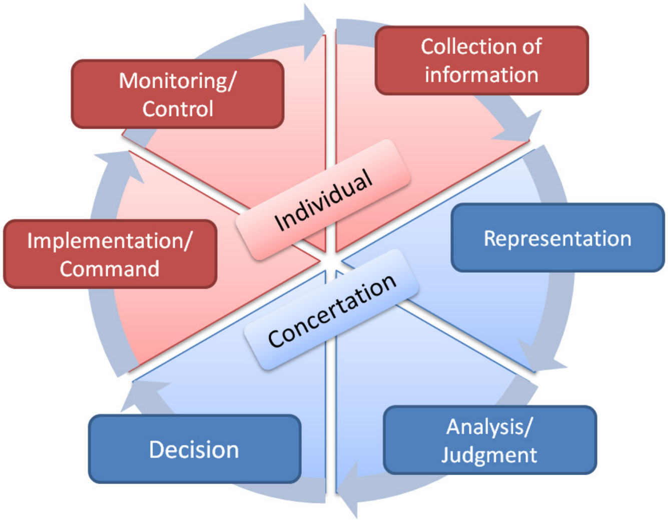


Figure 10 IBOBBO model (Van Mechelen, Brugghemans, & Bruelemans, 2015)

The consecutive steps are: Collection of information, Representation, Analysis/judgment, Decision, Implementation of the decisions/Command, and Monitoring/Control. The visual representation differentiates between 3 mono-disciplinary steps (individual) and 3 trans-disciplinary (concertation) steps.

2.3 Examples of modelling studies

Several studies have been performed meant for analyzing emergency response operations. For example Norros et al (2009) used Cognitive Task Analysis as a communication-oriented approach of defining *Common Operational Picture* as a joint cognitive system. In another case, a qualitative *Cultural Analysis* was used for developing a framework for design of technological support, in purpose of improving cross-organizational communication in a mass casualty incident (Wucholt, Yildirim-krannig, Mähler, Krüger, & Beckstein, 2011). During-incident process assessment (DIPA) is another initiative for guiding decision-making during an incident and claims to be suitable for emergency situations, where a high-degree of dynamics and information-lacking is present (Chen et al., 2012).

The chapter contains more examples of modelling studies.

2.3.1 Police strategies for resilient decision making and action implementation

Van den Heuvel, Alison, and Power (2012) present a study where they have attempted to model police decision-making and coping strategies in a police hostage negotiation process. Although the aim of this study was primarily to test the use of conscious coping strategies, the authors also included a model of decision-making that has several more general features. Previous studies from the same authors have identified three stages of critical incident decision-making, situation assessment, plan formulation and plan execution. When decisions must be made under difficult circumstances, much work goes into coping with uncertainty.

Lipshitz and Strauss (1997) have suggested three basic types of such uncertainty, namely inadequate understanding, incomplete information and undifferentiated alterantives. Making decisions in dynamic settings demands that decision-makers constantly reflect on, revise and update their mental models and assessments of a situation. This allows them to update their strategies and makes uncertainty more manageable. The model presented by Van den Heuvel et al can be seen in Figure 11. It describes the general flow of operational decision-making and also a number of coping strategies; reflection-in-action, reduction, suppression, assumption-based reasoning, weighing pro's and con's, delay/omission and forestalling. These strategies have been observed in real-world cases and can have both positive and negative contributions to decision-making.

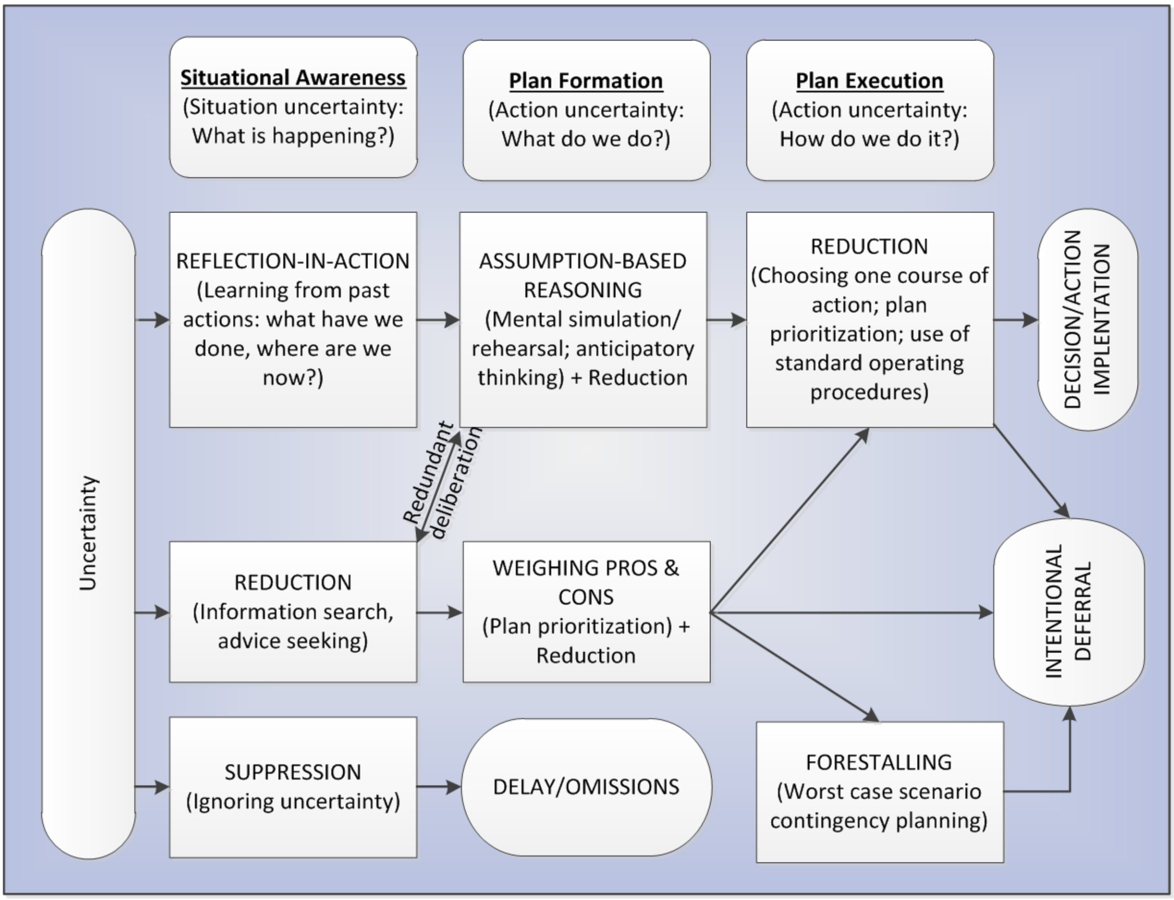


Figure 11 Model by van den Heuvel et al. (2012)

2.3.2 Collaborative Decision-Making in Emergency and Disaster Management

Kapucu and Garayev (2011) have examined the response of Emergency Management Assistance Compact's (EMAC) to hurricanes Katrina and Rita in 2005. EMAC is an inter-state mutual aid agreement that is supposed to facilitate sharing of resources during and after disasters. Decision-making under this agreement naturally has many collaborative aspects. In order to perform this analysis the authors have developed a theoretical framework that incorporates basic factors that affect the cognitive and operational base of decision-making during emergencies. These factors include the *system* under which organizations and agencies operate, the *environment* and its situational factors, the *capacity* of participating actors to perform collaborative duties and the *actors* themselves with their characteristics and relationships. This model corresponds to other NDM models such as RPD (see CascEff D3.2) in that it basically consists of one phase of perceiving the emergency and one phase of operating based on those perceptions. The model is reproduced in Figure 12.

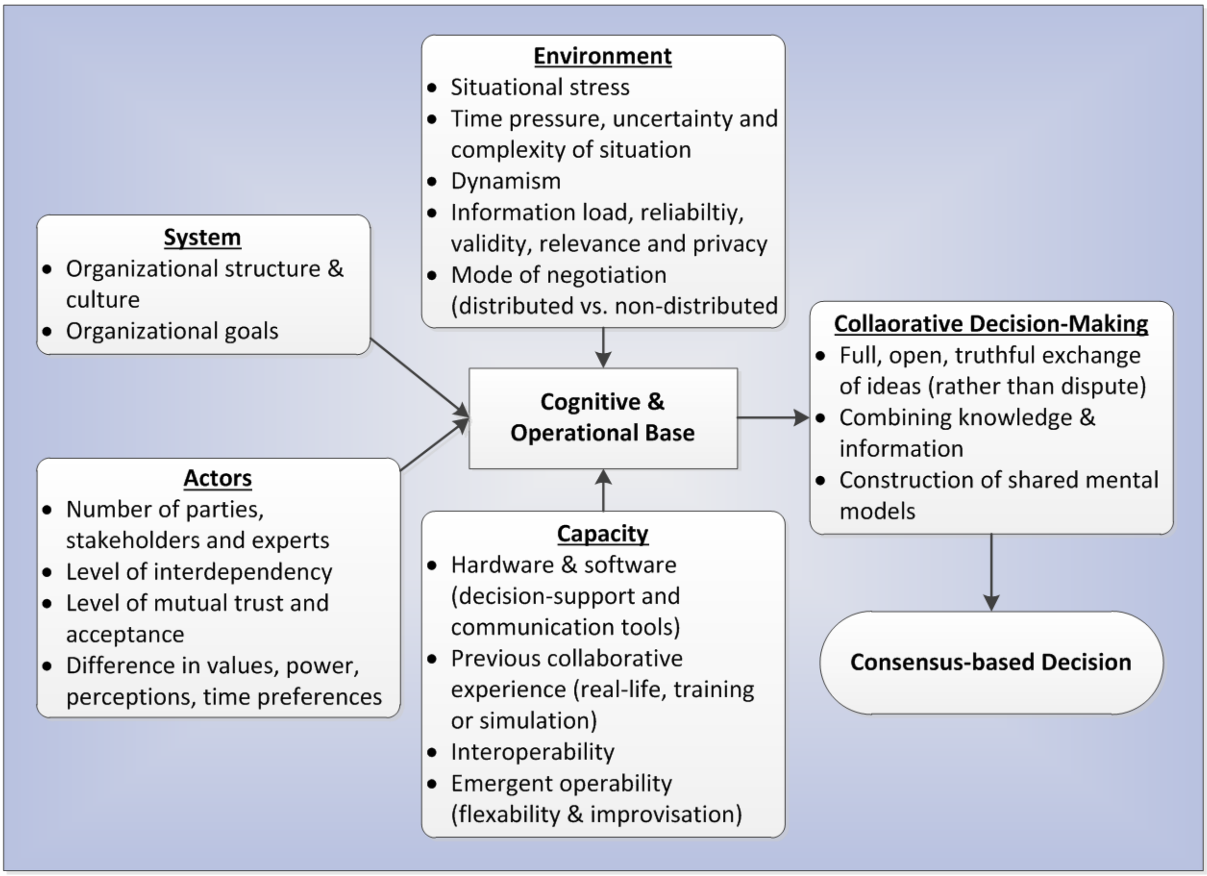


Figure 12 Model by Kapucu and Garayev (2011)

2.3.3 The 2013 Yarnell wildfire

In 2013 Yarnell, Arizona, became the scene of a large-scale wildfire that would ultimately claim the lives of the 19 members of the Granite Mountain Interagency Hotshot Crew. During this incident, the way that inter-organizational communication had been anticipated in the training manuals proved unworkable when the firestorm disrupted the responder communications system.

This incident has been analyzed by Hardy and Comfort (2015) in an attempt to recreate the information flow of responder decision processes. For this purpose the authors use computer modelling to expose interactions among physical conditions, technical support, organizational structure and individual cognition. The analysis is built on a comparison between information acquired from accident reports and operational documentation about firefighter training, incident command system organization, wildland fire management, and principles of suppression.

The computer models that were generated show interactions among key parameters of wildfire suppression and are meant to display how sudden changes in the wildfire interacted with technical weaknesses and sudden changes within the firefighting organizational structure. During the incident, information was not disseminated to all persons that required it (e.g. the fire crew that was lost) and problems with communications technology created misunderstandings around firefighter positions.

The first model in Figure 13 describes the main factors that are typically present in any wildland fire and shows the large scope that has to be encompassed by responder situation awareness. These are factors that have significant impact on the degree of coordination in the overall response organization.

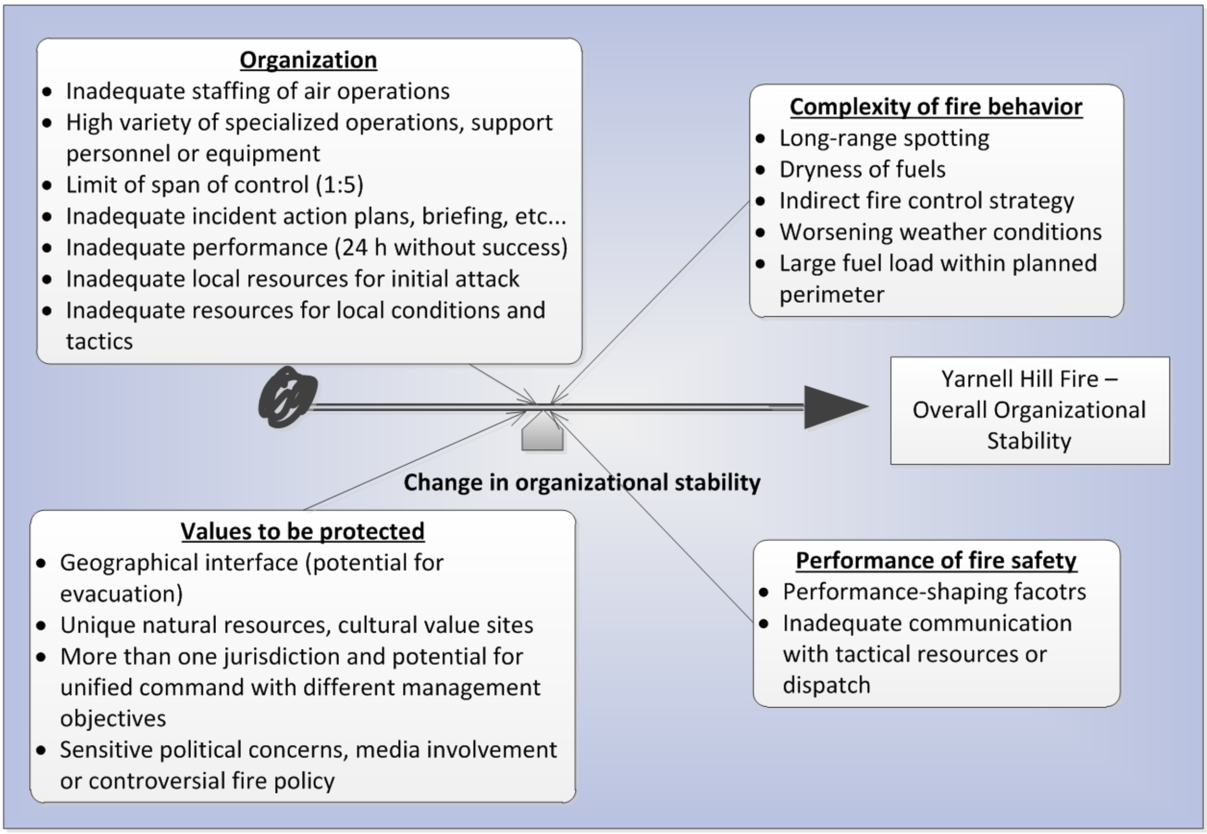


Figure 13 General Organizational Factors in Wildland Firefighting adapted from operational documentation. Adapted from NWCG (2014)

3 Decision-making flowchart development

In Appendix A the model of decision-making and other cognitive processes in a potentially cascading emergency response situation is presented. The model is built on the theories presented in the report, in the CascEff D3.2, the model cases presented and also 5 interviews with fire brigade personnel, 3 Incident Commanders and 2 managers.

3.1 Page 1 - Joint response operation

On page 1 an introductory image is presented. The joint system of agents strives towards the same goal. They want, as an interviewed fireman expressed it; "*just solve the situation*". Most likely every agent involved wants the same. But both "(re)solving" and "situation" could, and should, be problematized further, as the report already implied. Cognitive processing guides and controls both the resolving part and the situational awareness part, within each agent and between them. Even "just" could be viewed from different perspectives, and action is always derived by a more or less complicated and demanding cognitive processing. The overall goal is of course operationalized into smaller targets, but here conflicting, parallel or multiple goals could conflict, and trade-offs are then necessary for further operations. It is likely that different agents have some diverse goals, which may lead to a strained common ground.

In the model each agent has an iterative circle (further explained on Page 2 in the Appendix). Between agents there are cognitive flows and interactions. It is within these interactions and couplings that opportunities and risk occur. An agent itself cannot be "risk prone", the adaptive work is natural due to limitations, uncertainties and constraints. The context is essential, and influence additional constraints and preconditions.

3.2 Page 2 – Cognitive processing within the Rescue Service

On page 2 a cognitive processing within an agent is enlarged. These processing are executed within each agent, but here rescue service is a representative example. The agent itself is also a joint system and human beings, technological artefacts and organizational artefacts perform combined. The human team macro-cognitive processing is important for rescue operations. In such a situation functions like identifying problems, diagnosing problems, sense-making, awareness, possible re-planning (due to result of evaluation), decision-making and coordination are essential, but at the same time hard to easily observe and measure. Perhaps that is one of the reasons why it exist a research-practice gap when performing analysis work regarding socio-technical system aspects (Underwood & Waterson, 2013). However, lack of modelling knowledge in the industry does not make macro-cognitive functions less essential.

The cognitive processing takes place among humans, but some functions and tasks can be allocated to an artifact, such as technical devices, procedures or material resources etc. The "weakest link" determines overall function performance, why it is important that artefacts support and not interfere human cognitive processing. Artefacts could be seen as *performance shaping factors.*

The artefacts are designed by humans. Far away from the agent's own organizations, and often long time ago, general preconditions as regulations and infrastructure were shaped. These artefacts create latent preconditions that affect the actual rescue operations. More nearby in time, regularly within the agent's organization, design decisions have been made regarding material resources (based on financial resources, decided on a local governmental level), organizational structure, technology devices, routines and procedures. How well these fit into a rescue operation depends on how well they support cognitive processing in that particular context.

Cognitive processing is iterative and there are several parallel cognitive processes at the same time, regarding different cognitive goals. Example on how these interact, see Figure 2, page 5. Note that the analysis process in reality is more complicated than shown in the flowchart. For every goal there is an understanding that controls the goal directed action (regarding cognitive goals). The action provides more information which modifies current local understanding and so on.

Cognitive processing is affected by for example cognitive biases, trade-offs between multiple goals but also a feeling that has been summarized as an anxiety. Interviewed fire men say that they sometimes feel a bit affected by thoughts on future investigations with the purpose to apply accountability. They are also aware of the risk of committing a procedure violation, especially since they also know that a detailed procedure never can be followed in a surprising situation, it seldom captures the contextual factors like for example surprising outcomes. Some respondents, preferably managers, are also aware of the risk of being misrepresented in media, maybe for making "the wrong decisions". It should be noted that a news agency, like every human agent, also is infected by cognitive biases and multiple targets when reporting news.

As mentioned above, the understanding that leads to decision-making and action, are disturbed and affected by emergency context factors. These factors could be summarized as emergence, damage, time constraints and "wickedness". A wicked problem (Rittel & Webber, 1984) is a problem that cannot be fully understood and described and spreads across actor and responsibility boundaries. The contextual factors cannot be influences by results of cognitive processing, the emergency cannot be less emergent or less wicked based on for example a single so called "key decision". Results of emergency operations may suppress consequences, but never the fundamental emergency characteristics and preconditions built into the emergency itself.

It can be concluded that when designing artefacts, the fundamental characteristics of both an emergency and the cognitive processing must be taken into account. The next page in the Appendix addresses challenges in artefact design.

3.3 Page 3 – Artefact challenges and inter-agent cognitive processing

The last page is divided into two parts. The first part is a continuation on the theme artefacts coupled to cognitive processing in combination with an emergency context. The second part is a visualization of inter-agent interactions, the establishment of a common ground for emergency operations and response.

Regarding challenges coupled to designing artefacts, interview respondent mentioned the frustration when technology devices or predefined procedures "*don't work*". Therefore, this aspect was further analyzed. It appears that most artefact are designed with the preconception that it exists an "objective correct common picture and the job is just to find it, follow it, and then the emergency wickedness and emergence could be controlled and eliminated", followed by the development of procedures in the purpose of controlling uncertainty and adaptivity. The risk is that such an artefact is built upon an inaccurate image of real work challenges and success factors. As mentioned before such an artefact may not support cognitive processing, probably rather disturb and interfere. Then cognitive capacity is then directed to understanding and trying to collaborate with the artefact, not directed towards the emergency situation. The procedure has failed, not the team when they couldn't follow it (Dekker, 2003).

Hollnagel often refers to the difference between **work-as-imagined** and **work-as-done** and the inaccurate assumptions (see for example Hollnagel & Woods, 1983) that may exist among designing engineers, regarding real work challenges and success factors. These thoughts were applied on artefacts in emergency response, and interviews could confirm that it exists different images of rescue work outside and within the operative parts of the rescue service organizations.

The image of emergency work from the outside is often characterized by the belief that it exist an objective image of the assumed objective and predictable scenario. From the inside, fire fighters and commanders tell the story of constant surprises, and the only thing they can lean against is the rigorously trained defined moments put together to a unique whole by an overall experience. Every crisis then develops in an exclusive manner. They also explain that sequential procedures and plans seldom match these circumstances, procedures are often discarded in real emergencies. One fireman said that sometimes big coordination drills and rehearsals connected to large infrastructure facilities takes more time than it would have in a real emergency scenario. The reason is that they are more committed to following the rules. Thus, most procedures and routines are not applicable in a real emergency, presumably due to inappropriate design. The situation described by the interviewed fireman also confirms that cognitive capacity is stolen by the poorly designed artefact, this since the operations take way much more time than it would in reality. In reality the fire brigade knows that it is no idea to try to follow procedures and they fully rely on their own experience and practice based capacity. These findings are important when designing the Incident Evolution Tool (IET), the tool, or maybe the "emergency support" not necessarily in the form of a computer tool, must enable human team cognitive processing, not constrain it.

On the right side of Page 3 a cognitive processing between agents is described. The visualization is built upon the work of Norros et al (2009), with the purpose to create a common operational picture, or as they called it, a common ground. The picture describes action as adaptive and enlightens the interactions between groups. Norros et al found that the Incident Commander (IC) seldom views the accident, the IC stays in the car and communicates with rescue team and the staff function back at the station. The IC's image of the situation is therefore built upon the understanding from the executing personnel. This is a habitual approach that the brigade feels comfortable with and often it is successful. Volunteers could have e different understanding and different goal compared to the rescue brigade, and then act in other means. A need to being able to include volunteers in the operation is identified, this because volunteers are a big asset, and of course, volunteers without the same common ground as the rest of the team could be a potential problem, for example if they worsen the accident or injure themselves in any way. The response operation then has to be redirected. The visualization of the inter-agent interactions shows the feedback and feedforward loops that also exist within each agent's cognitive processing. Present action is built upon previous action that depends on previous understanding and so on. For every action there is feedback and the new understanding leads to new decisions and actions.

4 Development of decision support tools

Emergency response decision making respectively is characterized by (Inge Svedung & Rasmussen, 2000):

- The problem cannot be entirely defined. Emergency response decision making is related to a large amount of potential scenarios
- The decision makers are difficult to identify in advance, they depend on the nature of the accident
- Several organizations may be involved and resources may belong to different actors and decision making needs to be collaborative
- Information needed for decision making may originate from several different sources

In the development of decision-making support, in this case shaped as a computer based tool, some aspects need to be considered. First, how the organization of different databases and information sources is managed, second, how the ever evolving networks of actors and their need for communication and corporation are handled. The decision support has to capture and be designed for meeting the nature and work space for emergency personnel, the improvisation, collaboration and constantly change that a cascading emergency manifests (Inge Svedung & Rasmussen, 2000).

Furthermore, the amount of information in an emergency situation is likely to overwhelm both humans and computers. A computer based tool must share the same goals as the human team. Otherwise the tool itself can bring additional complexity to the emergency situation and fail to support human decision-making (Norros et al., 2009). An emergency situation is not a stable routine condition, especially not in escalation cascading situations. Such a complex socio-technical system puts high demands on a tool or decision support. Emergency situations cannot be foreseen by designers and sometimes not even by experienced rescue personnel (Naikar, 2010). Thus, in some emergencies the experts become novices. The tool must capture even this.

The computer based tool and the human team must share the same cognitive models, which are based on shared goals (Hollnagel & Woods, 1983). Kokar and Endsley (2012) call the cognitive models *computer model* (computer agent) and *mental model* (human agent), se Figure 14. They also suggest applying a, hopefully, shared ontology between human agent and computer agent. They conclude that such an ontology must be further developed for emergency response specifically. This is highly important due to the importance in adding contextual factors under the premise that actions only can be understood in their context (Palmqvist et al., 2012).

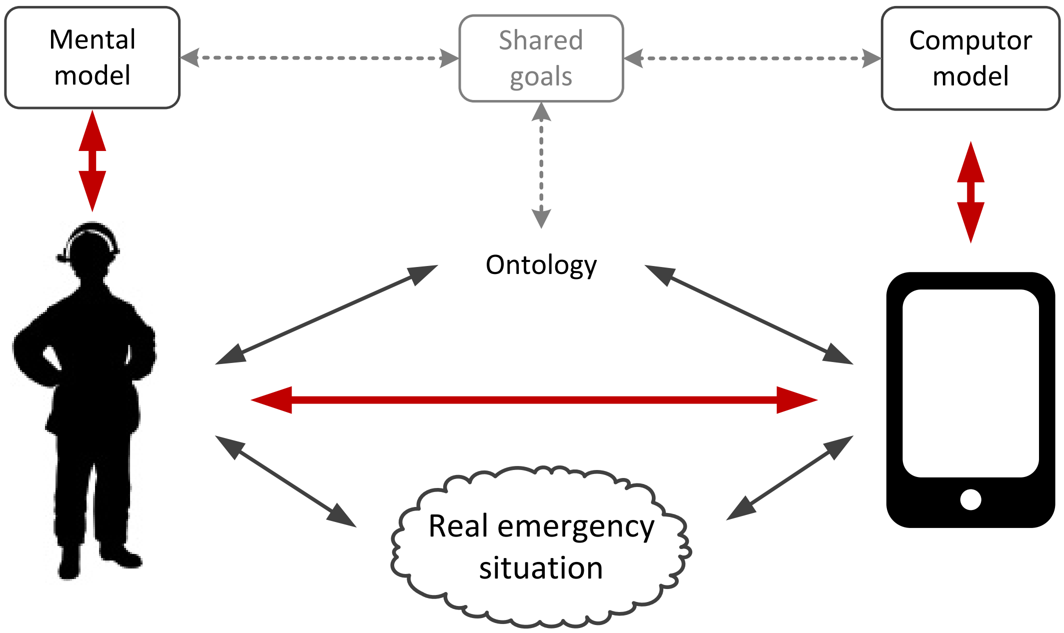


Figure 14 Collaboration between human and computer-based tool (Kokar & Endsley, 2012)

When (joint) cognitive systems engineering was introduced, through Hollnagel's and Woods' contribution "new wine in new bottles" in 1983, they likewise argued that the human being and the computer/machine must share the same goals. The "new" (Hollnagel & Woods, 1983) was a mental or cognitive aspect of designing machines. Machines had had a long history of being adapted to the human being's physics, not her cognitive abilities and limitations. Hollnagel and Woods argued that a new design approach was necessary for developing machines/computers that added meaning to the situation, in which humans had to interact with them. The designing engineer must recognize human being and system limitations and abilities on a cognitive level and start to get "aware" of the own assumptions about human and system cognition. Otherwise the unidentified assumptions will be built in into the model, without anyone knowing how it will affect the use or the user. An emergency already poses a strained situation, and a computer tool must definitely support the team's function and decisions, not add more complexity to the situation. Therefore, the main design criteria for decision support or a tool in an emergency situation, is the actual contextual factors (Palmqvist et al., 2012).

When cognitive models and the goals connected to cognitive functions don't match between human being and computer/machine/tool, it can result in failure and errors. Failures that we think is due to human error is actually design-induced and connected to poor design (McIlroy & Stanton, 2011). Often when an initiative to make software is made, assumptions that human macro-cognitive functions, like decision-making, easily could be transformed into real and usable representation are made. Or assumptions that human beings easily could be replaces by a computer tool (Zachary et al., 2012). Therefore, it is important that the tool gets properly informed by macro-cognitive aspects in emergency response, not just influenced. Valuable information lies in paths that emergency personnel form without someone else putting a tool in their hand. The human is not a passive user of a tool, she is a problem-solver. Development of decision-making support must start with a principle- and problem-driven approach, not that much a technology-driven approach (Woods & Roth, 1988).

4.1 Approach for informing the IET

Through the theory chapters in CascEff D3.2 and in chapter 2 of this report we have learned that high demands are put on a technology artefact in a joint cognitive system, especially under the pressure of an emergency situation. The tool must support human and system macro-cognitive work, the tool should motivate and not frustrate. The tool should help practitioners achieve their goals, not make them fight against poorly designed technology. A not satisfactory designed tool could add complexity to the situation and potentially affect the situation in a negative way (Norros et al., 2009).

A conventional engineering design process may leave a lot of loopholes concerning the role of the human being and especially her individual mental processing and, as mentioned before, the cognitive processing. Therefore, when designing the tool, an embedded Human-System Interaction design process is suggested, a process which is coherent with Wilson's (2014) system perspective characteristics. In this chapter a suggestion for such an approach is presented.

4.1.1 Generic design process

First a generic iterative design process is presented. The iteration is important for better match towards real work and for optimizing design (Andersson, 2014). Moreover, all implemented technology artefacts change the system, since it is joint and performance originates from overall performance. A technology artefact cannot be evaluated on its own without its context (Woods & Roth, 1988).

All of the presented models in chapter 3.2 are applicable for determining design demands, but some of them more or less through different phases. However, to "tweak" models for a better fit to specific project needs are quite common among Human Factors Practitioners (Andersson & Osvalder, 2015), therefore a specific customization and adaptation for CascEff is appropriate. In Figure 15 a suggestion for design process is presented. The design process contains of a big iteration and a small iteration.

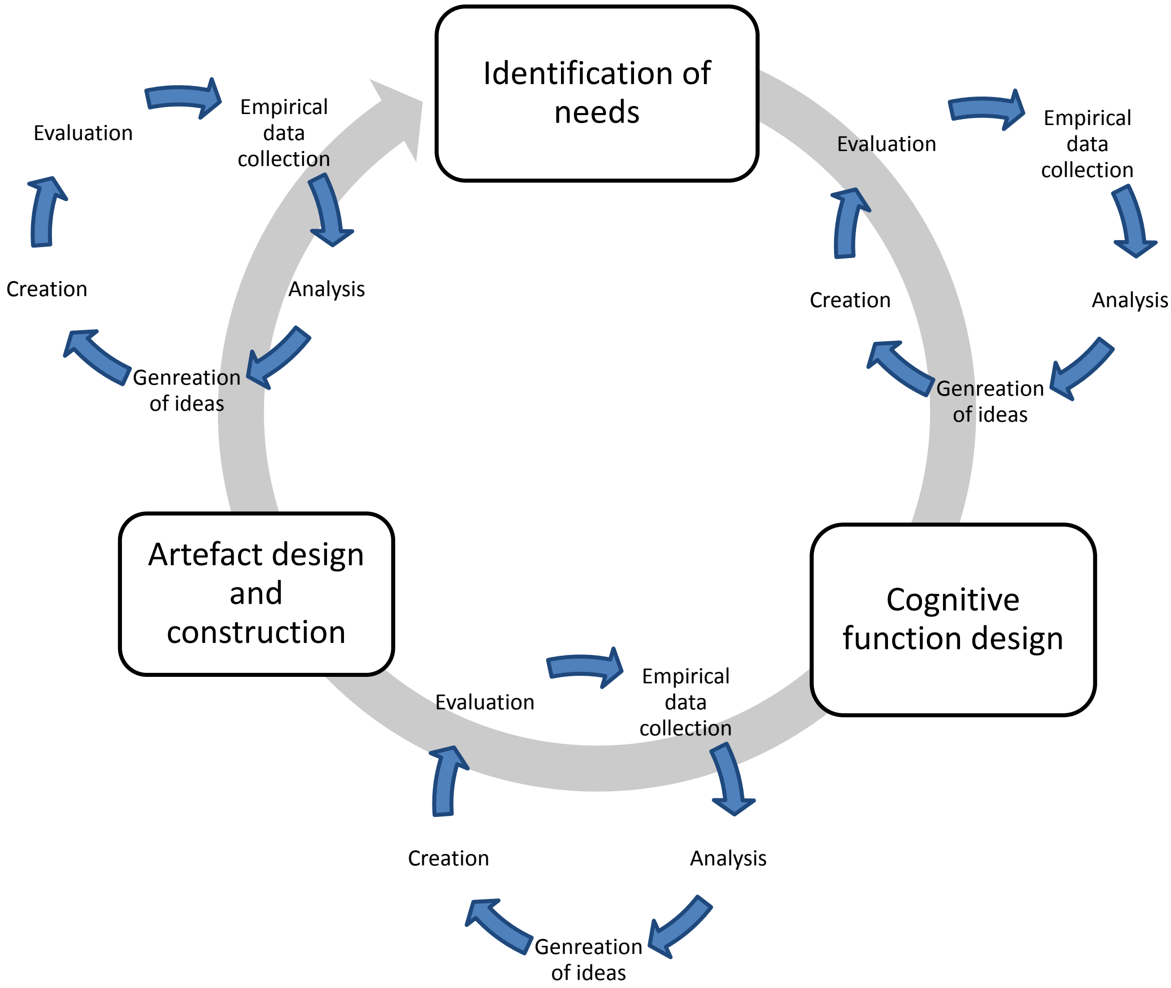


Figure 15 A design process suggested for developing the IET within the CascEff project.

The design process should address the still unsolved questions about developing support functions, maybe in the form of a computer based tool, that matches cognitive demands, enhances cognitive processing success factors and not steals cognitive capacity from the important analysis process of the emergency situation. The design process, with an essential involvement by real work practitioners, must be performed by skilled Cognitive Systems analysts with an understanding of macro-cognition. The analyst cannot be replaced by an instruction, checklist or standard (Zachary et al., 2012).

4.1.1.1 The big iteration

A design approach where micro-cognitive functions are applied to an already decided technological solution is not always appropriate. Nor are the historical, but yet established, interpretations of human factors satisfying. These consist of strategies of limited shaping of interfaces, compensatory training and education and sometimes a try to completely replace of the human agent through automation. It is important that the design steps involve macro-cognitive functions. Especially since these aspects are of greater interest in an emergency situation. With time constraint, cascading effects, wickedness and damage there is no room for wasting cognitive capacity on artefacts that aren't designed properly.

The iteration implies that the overall system changes every time something is changed. The big iteration covers the entire artefact development phase and consists of identification of needs and requirements, function design, artefact design and construction. In CascEff the artefact won't be fully implemented, but when it is, the big iteration should be expanded with implementation, test and evaluation followed by new identification of new needs. The needs are then *new* because artefacts always change overall performance in the overall system somehow. Potter et al. (2006) summarizes the final evaluation in questions as:

- To what extent does the change create limitations to be worked around versus how much does the change stimulate improvement?
- How does the change affect awareness, does it broaden or narrow the field?
- In what manner does the change support work practices versus lead to new strategies and exploration of new capabilities?

Methods presented in this chapter are applicable, but maybe not in their entirety. In the next work package of CascEff it is suggested to pick among the presented methods. Parts of each method suit different parts of the design process.

4.1.1.2 The small iteration

The small iteration is conducted in every step of the big iteration. The iterations could be performed several turns. The iteration consists of empirical data collection, analysis, generation of ideas, creation and evaluation. Several methods could be connected to each step, and can be retrieved from the field of Human Factors and Joint Cognitive Systems Engineering.

5 Conclusions

It can be concluded that a systemic approach for modelling decision-making in emergency response is essential for capturing macro-cognitive functions like problem detecting, sense-making, re-planning, decision-making and coordination. At the same time it exists a research-practice gap. Linear sequential modelling of decision-making and emergency response is still common among public and industry actors.

It gap between real emergency work and the image of it was also found. From the outside it is easy, and perhaps appealing, to view rescue operations as sequential, rehearsed and simple actions. In reality emergency response is a demanding ongoing adaptive analysis and process.

An emergency response could be described as a joint cognitive system, highly influences by the emergency context characterized by emergence, damage, uncertainty, surprises, wickedness and time constraint. The overall performance is decided by the combined human and artefact performance, where the artefacts become performance shaping factors, since function fulfillment are allocated to both humans and artefacts. An artefact, like a procedure or technical device that is poorly designed, steals cognitive capacity from the analysis and processing of the human team. A poorly designed artefact could even redirect cognitive capacity to the extent that the team fails to understand and control the emergency situation, with potentially increased level of cascading damage as a result.

When developing an artefact like a support function or a tool, it is crucial to design it for matching real work. A design process is suggested and it is possible to couple detailed methods with each process step. A skilled practitioner is important when performing the analysis work, the knowledge about joint cognitive systems could not be replaced by a manual or instruction. The bullet lists in chapter 2.1 must be cared for in the analysis and design work. The modelling of team decision-making in emergency response (presented as flowcharts in Appendix A in this report) should also work as a precondition for context understanding in further design work of the tool.

Finally, it is important to inform the tool regarding all levels of cognitive processing, not only let it be influences or inspired. The design should further be principle-driven, not technology-driven.

6 References

Abrahamsson, M., Hassel, H., & Tehler, H. (2010). Towards a systems-oriented framework for analysing and evaluating emergency response. *Journal of Contingencies and Crisis Management*, *18*(1), 14–25.

Andersson, J. (2014). *Representing Human-automation Challenges: A Model Based Approach for Human Factors Engineering in Industrial Practice*. Chalmers University of Technology. Retrieved from http://publications.lib.chalmers.se/records/fulltext/196377/196377.pdf

Andersson, J., & Osvalder, A.-L. (2015). *Method characteristics for viable human factors engineering practice*. Gothenburg.

Bye, A., Hollnagel, E., & Brendeford, T. S. (2000). Principles for Modelling Function Allocation. *International Journal of Human-Computer Studies*, *52*(2), 253–265.

Chen, A., Chen, N., & Li, J. (2012). During-incident process assessment in emergency management: Concept and strategy. *Safety Science*, *50*(1), 90–102.

Crandall, B., Klein, G. A., & Hoffman, R. R. (2006). *Working Minds: A Practitioner's Guide to Cognitive Task Analysis*. MIT Press.

Dekker, S. (2003). Failure to adapt or adaptations that fail: contrasting models on procedures and safety. *Applied Ergonomics*, *34*(3), 233–238.

Endsley, M. R., Hoffman, R., Kaber, D., & Roth, E. (2007). Cognitive Engineering and Decision Making: An Overview and Future Course. *Journal of Cognitive Engineering and Decision Making*, *1*(1), 1–21.

Hardy, K., & Comfort, L. K. (2015). Dynamic decision processes in complex, high-risk operations: The Yarnell Hill Fire, June 30, 2013. *Safety Science*, *71*(A), 39–47.

Hollnagel, E. (1993). *Human reliability analysis: Context and control*. Academic Press.

Hollnagel, E., & Woods, D. (2005). *Joint cognitive systems: Foundations of cognitive systems engineering*. CRC Press.

Hollnagel, E., & Woods, D. D. (1983). Cognitive systems engineering: new wine in new bottles. *International Journal of Man-Machine Studies*, *18*, 583–600.

Hutchins, E. (1995). *Cognition in the Wild*. MIT Press.

Kapucu, N., & Garayev, V. (2011). Collaborative Decision-Making in Emergency and Disaster Management. *International Journal of Public Administration*, *34*(6), 366–375.

Kokar, M. M., & Endsley, M. R. (2012). Situation awareness and cognitive modeling. *IEEE Intelligent Systems*, *27*(3), 91–96.

Kontogiannis, T. (2012). Modeling patterns of breakdown (or archetypes) of human and organizational processes in accidents using system dynamics. *Safety Science*, *50*(4), 931–

944.

Leveson, N. (2004). A new accident model for engineering safer systems. *Safety Science*, *42*(4), 237–270.

Lintern, G. (2010). A Comparison of the Decision Ladder and the Recognition-Primed Decision Model. *Journal of Cognitive Engineering and Decision Making*, *4*(4), 304–327.

Lipshitz, R., & Strauss, O. (1997). Coping with Uncertainty: A Naturalistic Decision-Making Analysis. *Organizational Behavior and Human Decision Processes*, *69*(2), 149–163.

McIlroy, R. C., & Stanton, N. A. (2011). Getting past first base: Going all the way with Cognitive Work Analysis. *Applied Ergonomics*, *42*(2), 358–370.

Militello, L. G., & Hoffman, R. R. (2008). The Forgotten History of Cognitive Task Analysis (pp. 383–387). Human Factors and Ergonomics Society 52nd Annual Meeting, Human Factors and Ergonomics Society, Inc.

Naikar, N. (2010). *A Comparison of the Decision Ladder and the Recognition-Primed Decision Model*. Melbourne, Australia.

Neisser, U. (1976). *Cognition and reality. Principles and implication of cognitive psychology*. QH Freeman.

Nja, O., & Rake, E. L. (2009). A discussion of decision making applied in incident command. *International Journal of Emergency Management*, *6*(6), 55–72.

Norros, L., Hutton, R., Grommes, P., Colford, N., Liinasuo, M., & Savioja, P. (2009). Analysis of work demands of multi-agency emergency response activity for developing information support systems. In *European Conference on Cognitive Ergonomics: Designing beyond the Product - Understanding Activity and User Experience in Ubiquitous Environments* (pp. 7:1–7:5). VTT Finland.

NWCG. (2014). *Wildland Fire Incident Management Field Guide, PMS 210*.

Palmqvist, H., Bergström, J., & Henriqson, E. (2012). How to assess team performance in terms of control: a protocol based on cognitive systems engineering. *Cognition, Technology & Work*, *14*(4), 337–353.

Patterson, E. S., & Hoffman, R. R. (2012). Visualization framework of macrocognition functions. *Cognition, Technology and Work*, *14*(3), 221–227.

Potter, S. S., Woods, D. D., Roth, E. M., Fowlkes, J., & Hoffman, R. R. (2006). Evaluating the Effectiveness of a Joint Cognitive System: Metrics, Techniques, and Frameworks. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *50*, 314–318.

Rasmussen, J. (1986). *Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering*. New York, NY, USA: Elsevier Science Inc.

Rasmussen, J. (1997). Risk management in a dynamic society: A modelling problem. *Safety*

Science, *27*(2-3), 183–213.

Rittel, H. W. J., & Webber, M. M. (1984). Planning Problems are Wicked Problems. *Polity*, *4*, 155–169.

Salmon, P. M., Cornelissen, M., & Trotter, M. J. (2012). Systems-based accident analysis methods: A comparison of Accimap, HFACS, and STAMP. *Safety Science*, *50*(4), 1158–1170.

Salmon, P. M., Goode, N., Archer, F., Spencer, C., McArdle, D., & McClure, R. J. (2014). A systems approach to examining disaster response: Using Accimap to describe the factors influencing bushfire response. *Safety Science*, *70*, 114–122.

Sanderson, P., Naikar, N., Lintern, G., & Goss, S. (1999). Use of cognitive work analysis across the system life cycle: From requirements to decommissioning. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *43*(3), 318–322.

Stanton, N. A., & Bessell, K. (2014). How a submarine returns to periscope depth: Analysing complex socio-technical systems using Cognitive Work Analysis. *Applied Ergonomics*, *45*(1), 110–125.

Svedung, I., & Rasmussen, J. (2000). *Proactive Risk Management in a Dynamic Society*. *Karlstad: Swedish Rescue Services …*. Karlstad: Risk & Environmental Department, Swedish Rescue Services Agency.

Svedung, I., & Rasmussen, J. (2002). Graphic representation of accident scenarios: Mapping system structure and the causation of accidents. *Safety Science*, *40*(5), 397–417.

Underwood, P., & Waterson, P. (2013). Systemic accident analysis: Examining the gap between research and practice. *Accident Analysis and Prevention*, *55*, 154–164.

van den Heuvel, C., Alison, L., & Power, N. (2012). Coping with uncertainty: police strategies for resilient decision-making and action implementation. *Cognition, Technology & Work*, *16*(1), 25–45.

Van Mechelen, I., Brugghemans, B., & Bruelemans, B. (2015). *Help, een Crisis! Leidraad voor het crisisbeheersingsproces*.

Wilson, J. R. (2014). Fundamentals of systems ergonomics/human factors. *Applied Ergonomics*, *45*(1), 5–13.

Woods, D. D., & Roth, E. M. (1988). Cognitive engineering: Human problem solving with tools. *Human Factors*, *30*(4), 415–430.

Wucholt, F., Yildirim-krannig, Y., Mähler, M., Krüger, U., & Beckstein, C. (2011). Cultural Analysis and Formal Standardised Language — a Mass Casualty Incident Perspective. In *the 8th International ISCRAM Conference*. Lisbon, Portugal.

Zachary, W., Hoffman, R., Crandall, B., Miller, T., & Nemeth, C. (2012). “ Rapidized ” Cognitive

Task Analysis. *IEEE Intelligent Systems*, *27*(2), 61–66.

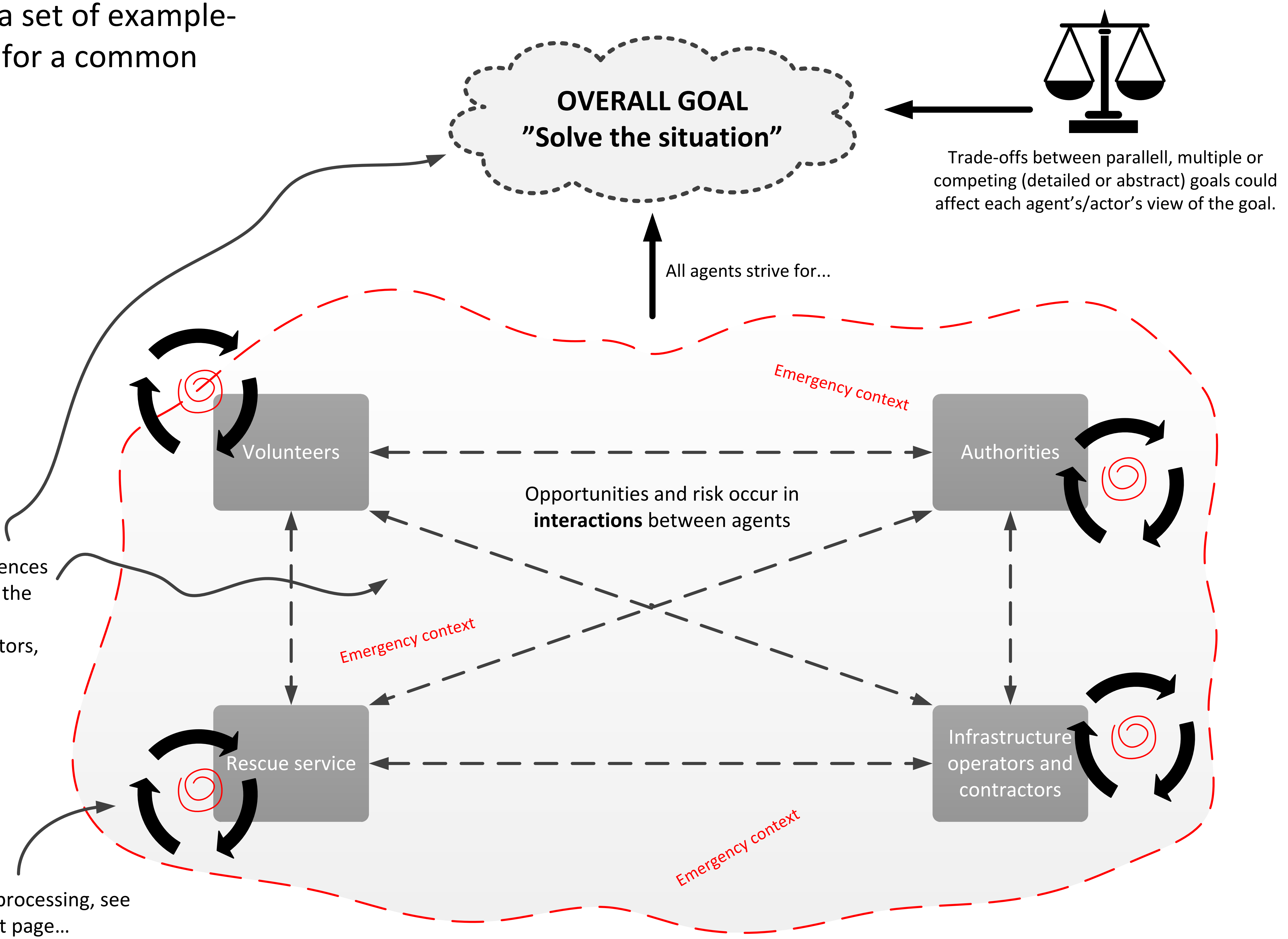
Appendix A

Visualization of emergency response in flowcharts

PAGE 1

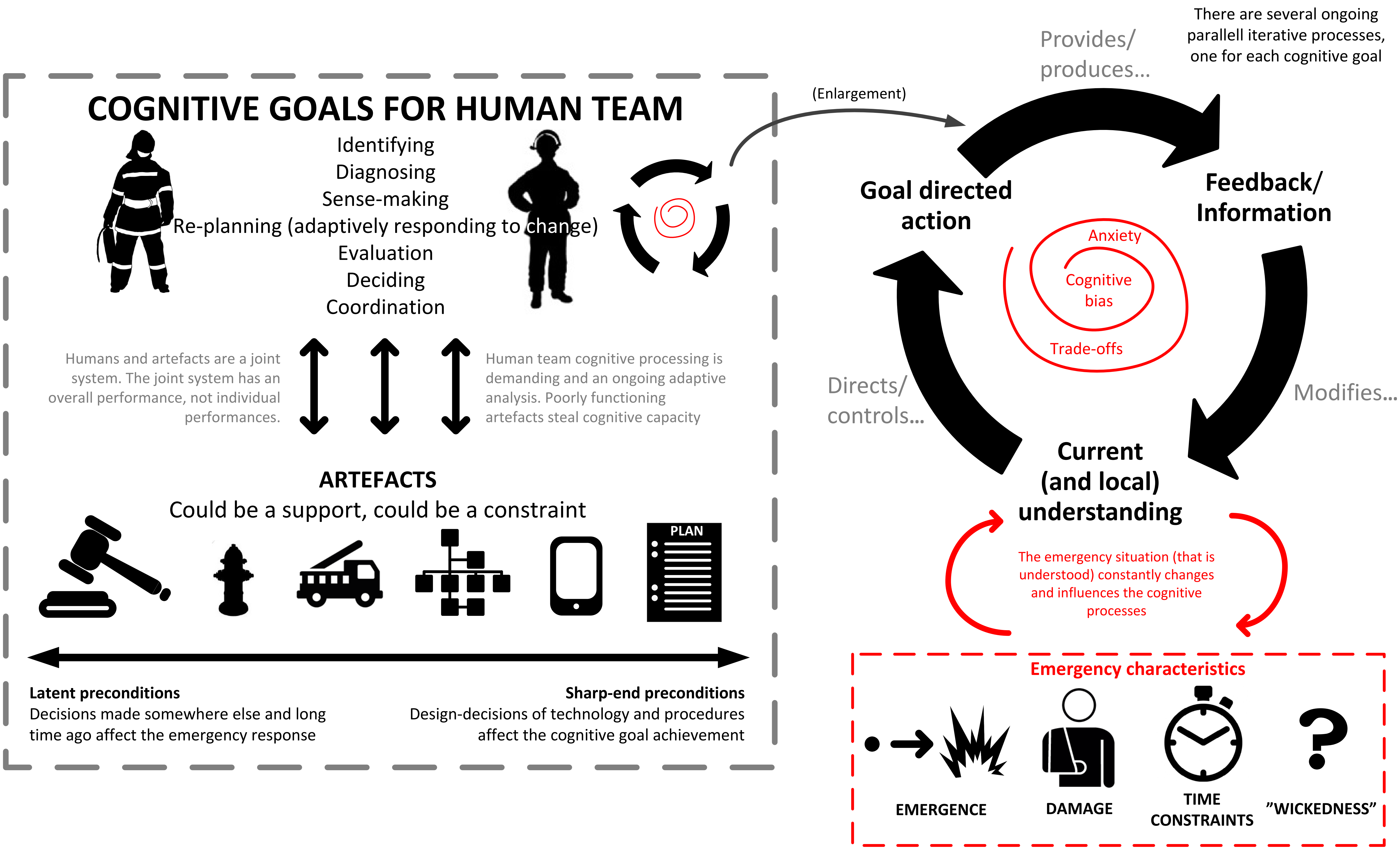
An overall emergency response operation with a set of example-agents, striving for a common goal.

Optimal paper size: A3



PAGE 2

Cognitive processing within an agent

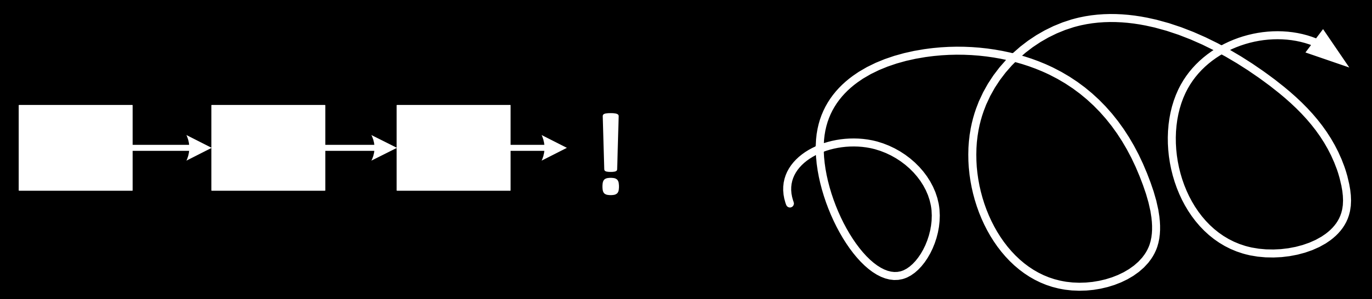


PAGE 3

Challanges connected to emergency cognitive processing between agents and artefacts...

It exists a gap between real cognitive work and the image of it

WORK-AS-IMAGINED	WORK-AS-DONE
There exist an objective understanding, the agents just have to find it	Every agent has an iterative cognitive processing leading to a local understanding
Emergency response input and utput is linear and sequential	Emergencys are emergent, outputs are expected to cascade
Emergency response is a simple rehearsed activity	Emergency response is a situation-unique continuous analysis
Following a plan, procedure and checklist leads to success.	Often are not surprises and real-work challenges captured in procedures, they can rarely be followed



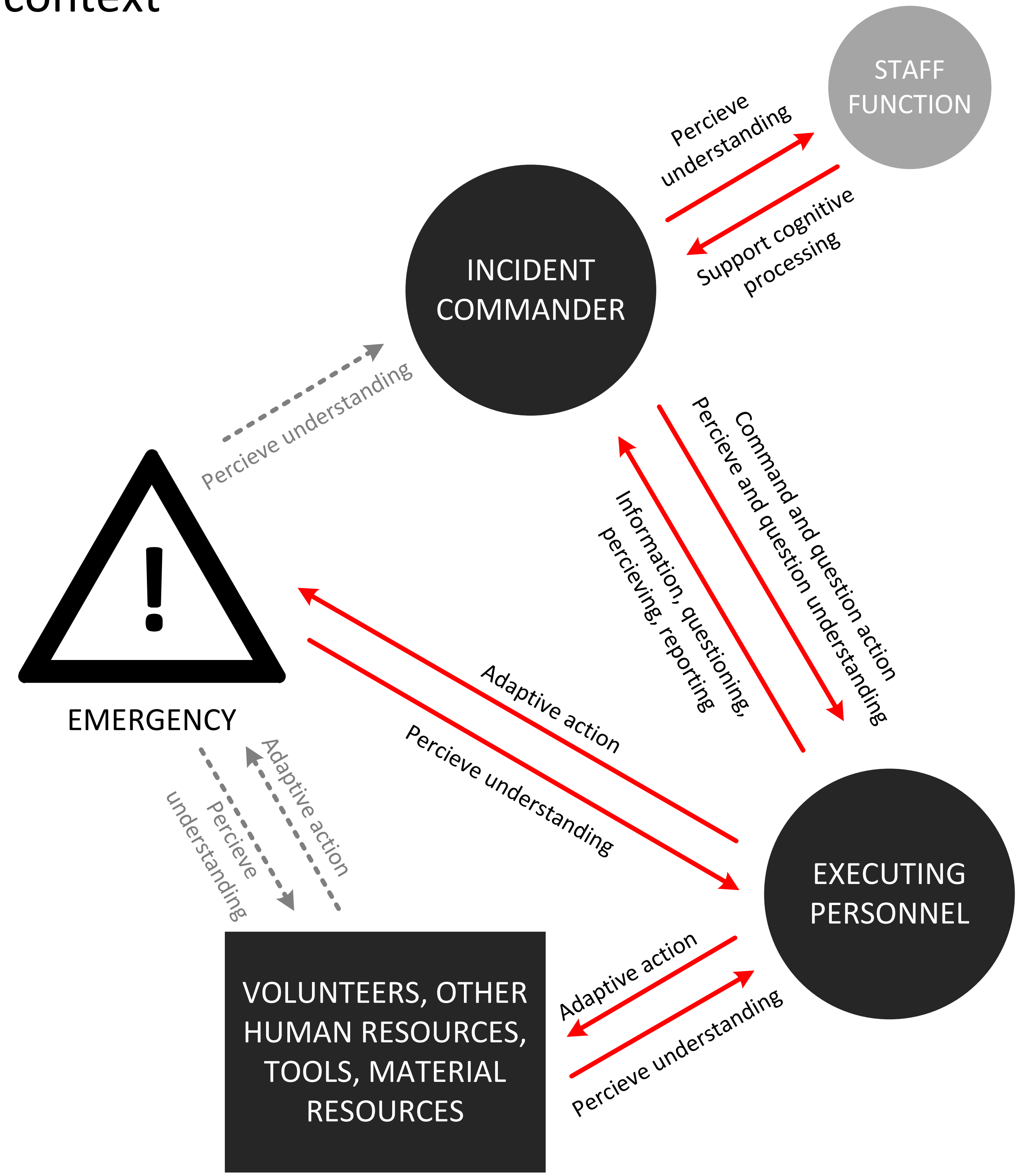
Artefacts are frequently developed on basis of work-as-imagined...

Leading to...

Non-applicable sequential procedures and poorly designed technology, stealing cognitive capacity

A reduction in cognitive capacity slows down cognitive processing, which could lead to failed understanding, diagnosing, decision-making, control and managing of the cascading effects

...and cognitive processing between agents and context



Action is adaptive and depend on availability of resources (time, manpower, information, material), emergency characteristics, trade-offs between multiple goals and interactions and flows between agents and artefacts