EXPLORING TACTICAL COMMAND AND CONTROL

A Role-Playing Simulation Approach

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ABSTRACT

This thesis concerns command and control work at the tactical level in emergency and crisis response operations. The presented research addresses two main research questions. The first question is whether it is feasible to simulate and study command and control work in the initial stages of response operations by means of role-playing simulations. If so, the second question is how to develop and execute role-playing simulations in order to explore this type of command and control work in a methodologically sound way.

The presented research is based on simulations as methodological means for qualitative research. The utilized simulation approach is scenario-based real-time role-playing simulations grounded in models of command and control work and response operations. Three simulations have been conducted based on this methodology and are reported in this thesis. Simulation I focused on the work practice of cooperating commanders whose activities may be enhanced by the use of artifacts. Simulation II concerned the issues of operationalizing advanced technological artifacts in rapid response expert teams. Simulation III gave attention to the role improvisation in command and control teams designated for international operations.

The results from the simulations and from the work conducted and presented in this thesis contribute with knowledge and experience from using role-playing simulations to study command and control work. This includes the methodological aspects of designing and conducting role-playing simulations such as scenarios, realism, evaluation and simulation format and control. It also includes the identification of the main application and problem areas for which the methodology is suitable, that is explorative qualitative inquiries and evaluation studies. The thesis provides new insights in command and control work with respect to adaptive behavior and improvisation. The thesis also identifies areas that need to be considered in order to further develop the role-playing simulation approach and its applicability.

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CONTENTS

INTRODUCTION

This thesis concerns command and control (C^2) work in emergency and crisis response operations. The presented research addresses two main research questions. The first question is whether it is feasible to simulate and study C^2 work in the initial stages of response operations by means of role-playing simulations. If so, the second question is how to conduct role-playing simulations in order to explore this type of C^2 work in a methodologically sound way. In particular, attention is given to tactical C^2. The tactical C^2 level concerns the overall management of response operations. This includes, for instance, the determination of goals of the ongoing operations, allocation of tasks and resources, and coordination of activities. The presented research is based on simulations as methodological means for qualitative research. The utilized simulation approach is scenario-based real-time role-playing simulations grounded in models of C^2 work and response operations. This chapter presents motivation for the research focus of this thesis and the methodological approach. The chapter also defines the research questions and objectives, summarizes the main contributions, and provides an outline of the thesis.

1.1 Motivation

Response operations take place shortly after emergencies or crises have occurred. They are carried out to save lives and to protect properties and the environment. They contain multiple goal-oriented activities that aim to mitigate the harmful consequences of emergencies and crises. A challenging aspect of emergencies and crises is their dynamic and complex nature. Emergencies and crises are characterized by a low-degree predictability of the rate and magnitude of their change, as well as the temporal properties of this change.

An example of such dynamics can be weather changes resulting in rain during a response operation to a forest fire that may significantly change the nature and progress of the response operation. Potentially, the rain slows down spreading of the forest fire but the rain water may wash away ash from the burned areas to water reservoirs. In this case, the objectives of the response operation are primarily concerned with fighting the forest fire while, at the same time, protecting the drinking water sources.

This example demonstrates that it could be difficult to anticipate whether emergencies or crises will escalate or suddenly change their nature as well as when, and how fast, this change will take place. Conducting response operations is one of the most challenging tasks in terms of how to gain and maintain control of the ongoing emergencies or crises as well as to determine countermeasures to put in place during the response efforts.

The dynamics and complexity of emergencies and crises have implications for the way response operations are managed as well as how activities are coordinated. The response operations and C^2 work are characterized by loosely defined and shifting goals. Such goals can often be achieved in a variety of ways. Moreover, emergency and crisis responses are non-routine operations that often require a problem-solving behavior by the commanders. The commanders in charge of the response operations may need to prove flexibility but also capabilities to adapt and improvise. They may need to shift between different work modes, for instance, from employing standard operational routines to a more situation-driven management of the operations. The commanders may also need to switch between alternative organizational structures in order to effectively coordinate the deployment of resources. Such adaptations may emerge on an *ad hoc* basis. But they can also by founded in a formal doctrine such as the, so called, incident command system. In summary, activities related to C^2 in emergency and crisis response operations are often very complex.

A challenge of the research on C^2 work in response operations is (a) to explore human behavior, and (b) to gain insights into C^2 processes with respect to their dynamics and complexity. For instance, it is difficult to fully exploit the issues related to C^2 work, where geographically distributed commanders act under varying circumstances, and operate and communicate through diverse types of technological artifacts. Response operations are thus rarely reviewed in sufficient details in terms of what happened and what was done for the research use, the design and development purposes as well as the learning and training needs.

Two methodological approaches have been central to the research of studying C^2 work in *naturalistic settings*, that is during real response operations: (1) ethnographical and (2) observational field studies. The *ethnographical study* (Wolcott, 1999; Atkinson et al., 2001) is a research methodology predominantly used in anthropology and in the social sciences.

Ethnographical studies build upon observations in the field. They focus on everyday activities of both individuals and social groups who share similar characteristics. In the context of C^2 work and response operations, this methodology has been used to study small groups, often at a single location, e.g., particular incident sites or command posts. For example, Landgren (2007) and Denef et al. (2008) focused on fire crews and their use of artifacts; Nuldén (2003) studied the work practice of police patrols in a similar way. Persson (2000) and Törnqvist (2004) investigated the work of C^2 personnel at C^2 centers and various command posts. The *observational field study* (Jorgensen, 1989) is a methodology commonly used in research fields such as cognitive science, ergonomics and human factors. The observational field studies and the ethnographical studies are two adjacent methodological approaches. The main difference between them lies in the relation of researchers to the studied humans. In the ethnographical studies, the researchers develop relations with the studied humans. While in the observational field studies the researchers maintain some professional distance and uses unobtrusive ways of collecting data. The observational field studies, similarly to the ethnographical studies, have focused primarily on small groups at single locations, in this case typically workplaces. For instance, Artman and Waern (1999), Garbis (2002), and Blandford and Wong (2004) studied diverse C^2 centers by using this methodology. The *reconstruction and exploration approach* (Jenvald, 1999; Morin, 2002; Thorstensson, 2008) is an example of how today's technologies in combination with models of response operations have allowed to extend the possibilities of the traditional research methodologies such as ethnographical and observational field studies. This approach utilizes traditional observations with thorough data collection supported by diverse information and communication technologies to document and explore real as well as simulated response operations (e.g., Ingrassia et al., 2005).

The ethnographical and observational field studies, especially when combined with the reconstruction and exploration approach, are recognized as methodologies providing accurate and rich pictures of what people do and how they interact in real life situations. These methodologies have, however, certain limitations with respect to their suitability when studying C^2 work in the emergency and crisis response operations. It is not possible to initiate or form the studied events and response operations. Due to the low frequency of emergencies and crises this type of studies can be time consuming with long waiting periods. The nature of the C^2 work may require many observers involved. At the same time, these observers may be put at risk when attending the incident sites (Bernard, 2000; Gould, 2001; Killian, 2002; Stallings, 2002; Lewis-Beck et al., 2003; Wheelan, 2005; Stallings, 2006; Nickens et al., 2008).

Simulations are often proposed as the most suitable methodology to explore and analyze C^2 work in emergency and crisis response operations (Brynielsson, 2006). Simulations address some of the limitations of ethnographic and observational field studies such as the possibility to form and initiate the studied events as well as to study distributed teams. *Microworlds* are an example of simulations that have been subject to studies of C^2 work in distributed settings. Microworlds are small-scale, low-fidelity computer simulations, providing computer-generated task environments that have complex, dynamic and opaque characteristics (Svenmarck and Brehmer, 1991; Granlund, 1997; Brehmer, 2004). Microworlds have been used, for example, to explore the different aspects of team decision-making and performance (Howie and Vicente, 1998; Granlund and Johansson, 2003; Jobidon et al., 2006), the cultural differences in teamwork (Lindgren and Smith, 2006; Lindgren, 2007) as well as to investigate the effects of information systems on situational awareness (Artman and Granlund, 1998; Johansson et al., 2007). *Full-scale simulations* of different operational activities and functions involved in response operations are another example. These simulations replicate situations, which have occurred or may occur in real response operations, as near to the reality as possible (Payne, 1999; Peterson and Perry, 1999; Perry, 2004). Mackenzie et al. (2007) used a full-scale simulation to study computer supported collaborative work between remote experts and onsite response teams. Woltjer et al. (2006a) focused on the use of communication technologies and the coordination of critical infrastructure failure recovery. Artman and Persson (2000), and Persson and Worm (2002) studied the impact of these technologies on collaboration, communication and teamwork.

Nevertheless, both these simulation methodologies face certain challenges with respect to their use to explore and study C^2 work in emergency and crisis response operations. In the case of microworlds it is, for instance, the overall task fidelity since the microworlds commonly utilize only pre-planned and fixed C^2 structures. Another problem is the issue of overfitting, that is the participants' adjustment to the specific features of the simulation and scenario (Granlund et al., 2001; Granlund, 2002). Realism in terms of the dynamics of decision-making is a problem in the full-scale simulations (Crichton et al., 2000; Crichton, 2001). In these simulations the participants often act and describe their actions in accordance with the operational procedures instead of performing rapid decision-making.

It is a rather complex task to develop and execute simulations of dynamic and non-routine situations such as the emergency and crisis response operations and the related C^2 work. This type of simulations needs to meet the combined demands of the research in naturalistic settings and in the field of simulations. The issue of concern is to determine whether the C^2 work conducted by the simulation participants is similar or corresponds well to the C^2 work in naturalistic settings. This means, for instance, that the simulations must involve professionals. It must be possible to utilize tasks, activities, and demands similar or identical to the real ones. The simulations must also be scalable so that real groups can be studied. The simulations must allow studies of work practice where various artifacts are used. The simulations must be repeatable in the sense that the set-up and scenarios are replicable. Though, the major challenge is that the simulations must allow the simulation participants to be adaptive and flexible, permitting different work modes as well as various organizational structures. This means that it has to be possible for the simulation participants to direct the development and changes in the simulations in a realistic way. A type of simulation that has the potential to allow for and to utilize this type of features and demands are so called role-playing simulations.

1.2 Research objectives

The presented research addresses two main research questions.

The first question is whether it is feasible to simulate and study C^2 work at the tactical C^2 level under described conditions and circumstances by means of role-playing simulations.

If so, the second question is how to conduct role-playing simulations in order to explore this type of C^2 work in a methodologically sound way.

The objectives of this research are defined as follows with respect to these two research questions:

- *To develop and execute* role-playing simulations, which would allow to study C^2 work at the tactical level in the initial stages of response operations.
- *To assess* if, how and to which extent role-playing simulations can be used to simulate C^2 work.
- *To explore and analyze* the C^2 work documented in the conducted role-playing simulations with respect to the research use as well as the design and development purposes.

1.3 Contributions

This thesis contributes to the body of research in the following four areas:

- Documented experience of designing and conducting role-playing simulations of C^2 work at the tactical level in the initial stages of response operations.
- Description of features and characteristics of the role-playing simulation approach for C^2 research as well design and development.
- Identification of application and problem areas the role-playing simulation approach is suitable for.
- Empirical findings concerning new insights in C^2 work with respect to adaptive behavior and improvisation.

1.4 Thesis overview

This thesis consists of a framework and a collection of four scientific papers. The framework provides introduction and background to the conducted research. It comprises the following chapters:

- The *Introduction* provides a brief background to the domain and describes the research problem.
- The *Theoretical background* describes the relevant theories and concepts and outlines the theoretical frame of reference of this thesis.
- The *Summary of studies* reviews the conducted role-playing simulations and the main findings.
- The *Discussion and conclusions* contain discussion, conclusions and suggestions for further research.

The collection of scientific papers contains the following publications:

- *Paper I:* Trnka, J., & Jenvald, J. (2006). Role-playing exercise – A real-time approach to study collaborative command and control. *Int. J. Intelligent Control and Systems*, *11*(4), 218-228.
- *Paper II:* Trnka, J., & Johansson, B. (2009). Collaborative command and control practice: Adaptation, self-regulation and supporting behavior. *Int. J. Information Systems for Crisis Response and Management*, *1*(2), 47-67.

- *Paper III:* Trnka, J., Kemper, T., & Schneiderbauer, S. (2009). Do expert teams in rapid crisis response use their tools efficiently? In B. Van de Walle, M. Turoff & R. Hiltz (Eds.), *Advances in Management Information Systems: Volume on Information Systems for Emergency Management* (pp. 126-159). Armonk, NY: M.E. Sharpe.
- *Paper IV:* Trnka, J., Lundberg, J., & Jungert, E. (submitted). A model-based simulation approach to study role improvisation of a command staff. *IEEE Transactions on System, Man, and Cybernetics, Part A: Systems and Humans*.

THEORETICAL BACKGROUND

This chapter describes a theoretical background, which represents the base for planning, preparation and evaluation of role-playing simulations of C^2 work in response operations. The theoretical background concerns the different theoretical foundations for C^2 work. This includes general concepts and models associated to C^2 such as the notion of control models, the team perspective and the constraint management. The theoretical background also describes empirical-based models and concepts for response operations, for instance, tactics, ways and forms of C^2 work, and communication modeling. The theoretical background reviews the issues related to modeling, simulation design, and simulation execution such as the model hierarchies, scenarios, realism and simulation control.

2.1 General models and concepts

This research is founded in the view of C^2 work in response operations as a *dynamic control* (Brehmer and Allard, 1991; Brehmer, 1992). The dynamic control viewpoint has been used both in emergency and crisis management as well as in the military domain (e.g., Morin, 2002; Svensson, 2002; Bakken and Gilljam, 2002; Johansson, 2003).

In dynamic control situations it is assumed that the so called *controller* is able and aims to gain and maintain control of a process. The process is a series of changes of an object, which can be a situation, system or other phenomena. The controller is required to make a series of decisions in order to gain and maintain control of the process. These decisions may be interdependent. They also need to be appropriate, taken in an appropriate order and at appropriate moments in time (Brehmer and Allard, 1991). Moreover, the controller has to have an appropriate construct of the object in change. The controller has to be able to observe the changes of this object over time. The controller also has to be able to affect the object; though the object may change autonomously too (Brehmer, 1992).

The viewpoint of dynamic control represents a fundamental standpoint in this research; it governs which general models and concepts are relevant in order to define universal assumptions and properties of C^2 work in response operations.

2.2.1 Control models

The notion of control models is a theoretical approach, which concerns dynamic control. Control models formalize the aspect of dynamic control when the controller is represented by a single entity, which can be a human or machine.

The basic cyclic model of control, described by Hollnagel (Hollnagel, 1993, 1998a, 1998b; Hollnagel and Woods, 2005), is one of such models, which aims to describe control work. In the model, which originates in Neisser's (1976) perceptual cycle, a cyclic process of control work contains a *controller* monitoring, detecting and assessing the state and changes in a process to be controlled. The controller's work can be seen as a process, which is considered as dynamic and complex as a consequence of the actions initiated by the controller as well as by external events (disturbances) triggered by unexpected causes. Based on the interpretation of the feedback, the controller plans or modifies the next actions in order to maintain control of the process. This choice of the next actions depends on the context and the competence of the controller. The cycle does not necessarily begin with an external event or stimulus; neither does it end with an action or response. The controller continuously adjusts the control work, based on the previous actions (responses) and prediction of the future actions (anticipations) (Figure 1).

There are other similar models in addition to the control models. These models, also called decision-making models, focus on control work of human controllers only. They aim to provide insights in aspects of decision-making such as perception, reasoning, rationality, and planning, as well as human limitations in control. Examples of such models are the OODA (Observe-Orient-Decide-Act) loop (Boyd, 1987), the SHOR (Stimulus-Hypothesis-Option-Response) model (Wohl, 1981), and the DDL (Dynamic-Decision-Loop) model (Brehmer, 2005). Mayk and Rubin (1988), Grant and Kooter (2005), and Stanton et al. (2008) make comparison of and discuss the different control and decision-making models.

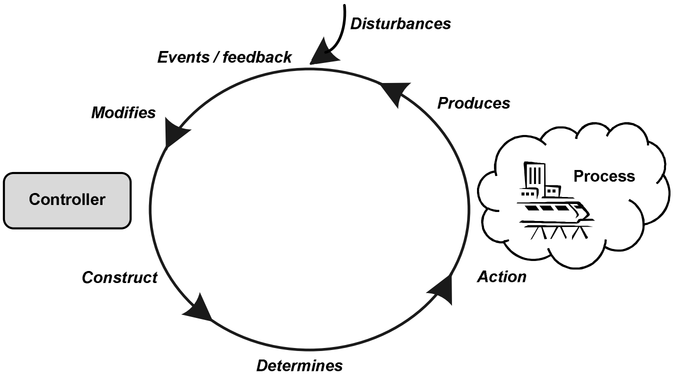

Figure 1: The basic cyclic model of control (adapted from Hollnagel and Woods, 2005).

2.1.2 Systemic descriptions

The *systems view* is another theoretical perspective focusing on the aspects of dynamic control. The systems perspective suggests that investigation of single parts and processes cannot provide a complete explanation of an object; attention also has to be given to the overall performance and causal relations (Von Bertalanffy, 1972). Over time the systems view has evolved in various theoretical approaches such as cybernetics (Wiener, 1948; Ashby, 1956), general systems theory (Boulding, 1956; Von Bertalanffy, 1968), control theory (Fitts, 1954; Ashby, 1968; Kelley, 1968), information theory (Shannon and Weaver, 1949; Miller, 1968), and so on.

The systems view has also been used to study objects and processes related to C^2 work in response operations (e.g., Brehmer, 1987; Svensson, 1998; Persson, 2000; Shattuck and Woods, 2000; Johansson, 2005; Woltjer, 2009). The commonly referred systems views in this context are: cybernetic systems, joint cognitive systems, and human activity systems. These system views describe the controllers as purposeful systems, involving groups of humans who may use diverse artifacts, and whose activities are interrelated.

Cybernetic systems

Cybernetics is a control-theoretical approach, which originates from the research by Wiener (1948), Shannon and Weaver (1949), and Ashby (1956). Cybernetics and the notion of control models are closely related since many of the control and decision-making models have their roots in ideas and concepts from cybernetics (Brehmer, 2005).

Cybernetic systems are seen as dynamic with self-regulative behavior and mutual causal relationships. Cybernetic systems must have the capacity to adapt their own behavior and structure not only according to their goals but also to the changing environment, and thus be adaptive (Wiener, 1948; Ashby, 1956). Moreover, cybernetic systems should have a variety that, at least, matches the variety of the processes in the environment to be controlled in order to gain and maintain control of these processes. This is also known as the law of requisite variety (Ashby, 1956). Cybernetics gives particular attention to the feedback loops, which are represented by exchanged messages carrying information, as means of control. In other words, cybernetics connects communication[I] and control (Wiener, 1948). Coordination, regulation and control using feedback loops are therefore key activities in cybernetic systems.

Joint cognitive systems

Cognitive systems engineering is an approach that evolved from cybernetics and cognitive science. Cognitive systems engineering focuses on phenomena that emerge when people use technological artifacts in their work (Woods and Hollnagel, 2006).

Joint cognitive systems (JCS) are systems operating by using knowledge about themselves and their environment, that is showing cognitive behavior. JCS are actively looking for information and their actions are determined by purposes, goals and intentions as well as externally available information and external events. At the same time, these actions depend on the resources and constraints that characterize the context in which the JCS act. This means that JCS are able to plan and modify actions based on their knowledge, to achieve their goals at every point in time, and thus control what they do (Hollnagel and Woods, 2005).

Properties and characteristics of JCS are seen as unique to each system rather than generic and common to all systems. The attention is given to the overall performance, behavior and external functions of JCS in relation to their environment and context (Woods et al., 1994; Hollnagel and Woods, 2005).

I) Shannon and Weaver's (1949) model describes communication as exchange of messages in the form of data (analogue and digital signals): information source – (*coding*) – signal – (*sending – transmitting – receiving*) – signal – (*decoding*) – destination (*interpreting/understanding*).

Human activity systems

Human activity systems (HAS) are a part of the soft systems methodology (Checkland, 1999). HAS are systems, which contain humans, use resources, and have specific purposes. HAS are parts of larger systems. HAS interact both with their environment and the systems they are a part of. HAS are purposeful systems designed by people. Besides being goal-seeking, HAS are characterized as systems maintaining relations (Flood, 2000; Checkland, 2000). As a result, HAS can change for other reasons than control needs, compared to cybernetic or joint cognitive systems, for example, because of the designers' intentions to improve relations in these systems (Checkland, 1999).

HAS are commonly represented by conceptual models, which are intellectual constructs of activities humans need to undertake in order to pursue particular purposes, including goals (Flood, 2000). These models are based on representative scenarios applied to the HAS, which link together key features and activities taking place within the studied systems in order to explore specific situations or events (Checkland, 2000; Vat, 2005). The models are specific for each individual HAS, and are always based on empirical observations of these systems (Checkland, 1999).

2.2.3 Constraints and context

Constraints represent relations between systems and their environment as well as among system parts (Ashby, 1968). Constraints can be seen as conditions such as restrictions, limitations, and regulations under which system behavior occurs. Constraints limit as well as provide opportunities for system behavior (Woltjer, 2005; Woltjer et al, 2008). In this context, the C^2 work can be seen as an enduring constraint management (Persson, 2000). The ability to manage the constraints and coordinate the actions within these constraints, determines if controllers are able to achieve their goals and to what extent (Persson, 2000; Woltjer, 2009).

Constraints can be described as physical, that is spatial and temporal relations between the systems or their parts, and their environment (Buckley, 1968). Constraints can also be of conceptual and abstract nature, for instance, representing organizational, cultural and strategic conditions (Ashby, 1968; Buckley, 1968; Daft, 1992). Constraints can be both general and specific. General constraints are related to the systems' universal properties. Specific constraints are dependent on the context.

Context is a set of facts on properties and conditions related to system behavior. These properties and conditions, including constraints, describe systems and their environment in particular situations and at given points in time. In other words, context describes explicit circumstances under which system behaviors occur. Context thus influences how systems behave as well as how they interact with their environment and other systems (Kokinov, 1995; Zacarias et al., 2007). Context is of temporary nature and is not stable, i.e., it is changing over time (Kokinov, 1995; Silverman, 1997; Hollnagel and Woods, 2005). Depending on the scope and level of analysis, context can be regarded in many dimensions such as in groups, organizations, professions, institutions, as well as in historical or political perspectives.

2.2.4 The team perspective

The *team perspective* is an approach to describe dynamic control, where human groups are involved. The team perspective is not a single scientific concept but instead it combines several other notions such as distributed/team decision-making (Rasmussen et al., 1990; Cook et al., 2007), distributed cognition (Hutchins, 1995; Garbis, 2002), and communication (Hirokawa and Poole, 1996; Frey et al., 1999). The notions related to teams and team processes give insights in interactions, activities, and processes taking place within the controller.

A number of assumptions need to be fulfilled to consider a group of humans as a team in a control situation. The involved humans, each considered as a team member, have to be engaged in a set of goal oriented activities, which are carried out in a collaborative manner (Orasanu and Salas, 1993). The team members' actions are interrelated and interdependent, and take place within the same time-framework (Orasanu and Salas, 1993; Brannick and Prince, 1997). The team members have explicit roles and tasks. They have access to different information and often use special artifacts (Thordsen and Klein, 1989; Artman, 2000).

Internal coordination and adaption processes

Dynamic control involves regulation of both the processes to be controlled and the controller itself (Brehmer and Svenmarck, 1995). In this case, the controller is represented by teams. How the teams' activities are organized and coordinated thus underlies the functioning and performance of the teams (Jones and Roelofsma, 2000).

Coordination represents a continuous management of dependencies in the teams through communication and/or team configuration (Brehmer, 1991; Fussell et al., 1998; Persson, 2000). Coordination through team configuration concerns changes in the teams' arrangements, for example, team structure, allocation of tasks, and use of artifacts. While coordination through communication means the ways and forms of communication used for negotiation and feedback (Fusell et al., 1998). At the same time, different configurations of teams influence the way and form of communication. This includes the quality and content of the exchanged messages as well as the type of communication taking place (Urban et al., 1995; Artman, 1999; Jones and Roelofsma, 2000; Driskell et al., 2003). Examples of the different configurations are (a) if the team members are gathered at one geographical location or spread across multiple locations, (b) hierarchical division of tasks and decision-making vs. networked organization of the teamwork, and (c) communication settings, meaning who is able to communicate with whom. In other words, team configurations are closely related to communication, and have an essential impact on the interaction, that is how the work is performed, and what the outcome is (Orasanu and Salas, 1993; Stout et al., 1999; Artman and Persson, 2000; Johansson and Hollnagel, 2007).

2.2 Controller in the real world context

In the real world, the controllers do not act in isolation but as a part of larger systems. These larger systems are commonly recognized as *command and control systems* (C^2 systems). From a general perspective, C^2 systems are distributed supervisory control systems (Shattuck and Woods, 2000). C^2 systems are designed and created to utilize coordination of the wide range of activities and the high number of different organizations, which characterize the present emergency and crisis management.

The core of C^2 systems are diverse *command and control units* (C^2 units), formed by one or more humans (e.g., commanding officers, experts, politically assigned decision-makers, and operators) and the technological artifacts they use (e.g., communication systems, databases, and planning systems). C^2 units in the C^2 systems can be described in terms of their goals, allocated authority, and responsibility. The conditions of the work of the C^2 units are also defined by the managerial structures within the particular C^2 systems and the emergency and crisis management organizations, in which the C^2 units are embedded. The C^2 units of the C^2 systems can therefore reach different levels of interdependence (Persson, 2004; Stanton et al., 2008). Compared to the military domain, the additional challenges specific for C^2 systems in emergency and crisis response are management of (a) resources of diverse kinds of organizations, (b) multiple goals of these organizations, as well as (c) their varying operational procedures (Wybo and Lonka, 2002; Shen and Shaw, 2004).

C^2 systems in emergency and crisis management as well as the military domain are characterized by high complexity with respect to the interactions combined with medium to low coupling between their parts (Perrow, 1984). It is thus often difficult to describe and compare diverse C^2 systems. The NATO Research and Technology Group SAS-050 (NATO, 2006) suggests a *command and control approach space* (Figure 2) to illustrate three independent variables describing key properties of any C^2 system. These variables are: allocation of decision rights, patterns of interactions, and distribution of information.

- The *allocation of decision rights* concerns distribution of authority across C^2 systems, and ranges on a scale from unitary, that is centralization of authority to one location or person, to peer-to-peer, which means equal decision rights to all.
- The *patterns of interactions* describe interactions taking place among the parts of C^2 systems, and range on a scale from fully distributed to fully hierarchical.
- The *distribution of information* is represented by communication in C^2 systems, and ranges on a scale from totally controlled to broad dissemination, where in the later case everyone has access to every information item.

These three variables are based on real distribution of the decision rights, communication and interactions. The values of the variables take into account both the formal and informal ways of C^2 work. There are also other aspects that may have an impact on these three variables such as norms, culture, and training (Alberts and Hayes, 2006; NATO, 2006; Stanton et al., 2008).

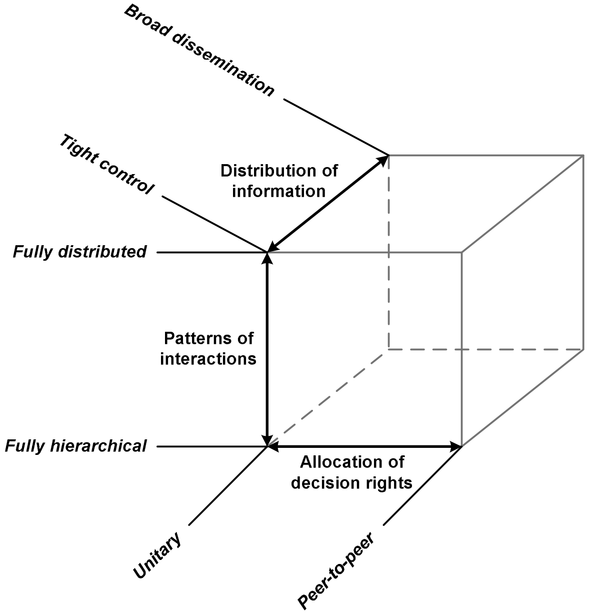

Figure 2: "Command and control approach space" as a way to illustrate the three independent variables, which characterize any C^2 system: (a) allocation of decision rights, (b) patterns of interactions, and (c) distribution of information (adapted from NATO, 2006).

The values of the variables in the C^2 approach space are changing over time as C^2 systems are dynamic in their nature (Alberts and Hayes, 2006; NATO, 2006). In other words, the values visualized in the C^2 approach space are characteristics of specific C^2 systems in particular situations and at given points in time. Moreover, ability of C^2 systems to operate differently across the C^2 approach space and to reach different values of the variables indicates adaptive capacity of the C^2 systems (NATO, 2006).

An important aspect of modeling C^2 work in response operations is how the controllers and their relations toward the C^2 systems as well as the environment are defined. The standpoint is that only parts of C^2 systems are involved in C^2 work in specific response operations. These parts of the C^2 systems, which control the progress of specific response operations, correspond to the controllers. The C^2 approach space and its variables indicate how and in what way the larger systems, meaning C^2 systems, may impact the controllers during response operations. It is thus important to take into account the impact of the C^2 systems on the controllers in terms of interactions, allocation of authority and communication as these three variables include the context and constraints under which the controllers act.

2.2.1 Boundaries and interactions

Controllers control the progress of specific response operations. As the duration of any response operation is time limited, the controllers exist on temporary basis as well (Figure 3). Besides the temporal boundaries concerning the existence of the controllers, there are boundaries and interactions with respect to the different types of C^2 work performed in the C^2 systems, and the temporal aspects of this work. Parts of the C^2 systems may need to operate on different time scales and maintain a certain amount of freedom of action to be able to perform effectively and achieve their goals (Brehmer, 1991; Brehmer and Svenmarck, 1995).

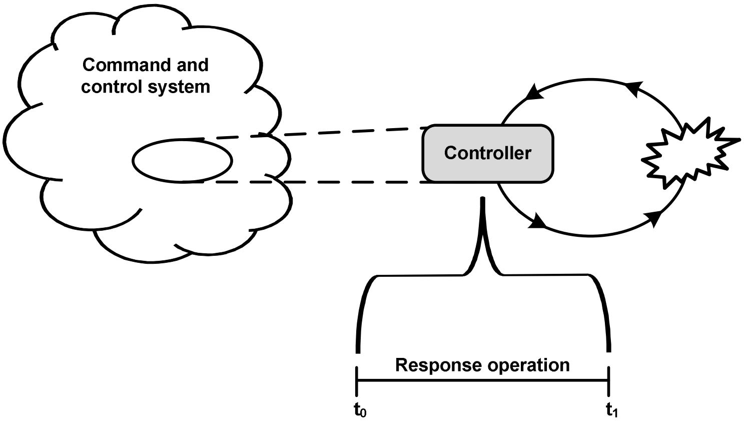

Figure 3: A controller of a specific response operation is in principle a subsystem, which is assigned to control a specific response operation, and which exists on a temporary basis.

The C^2 work in the C^2 systems is thus often described with the help of models. These models commonly contain three *command and control levels*[II] to distinguish the C^2 work on the different time scales (Figure 4) (Fredholm, 1997; Cedergårdh and Wennström, 2002; Svensson et al., 2005; Cedergårdh and Winnberg, 2006; UK CCS, 2007; Atkinson and Moffat, 2007): strategic, tactical, and operational.

- The *strategic C^2 level* operates on the longest time scales. It concerns, for instance, descriptions of general roles within the C^2 systems, definitions of frameworks for response operations, and dimensioning of resources over time and space.
- The *tactical C^2 level* concerns the overall management of specific response operations, and is represented by the controllers. The tactical level of C^2 includes, besides others, determination of goals of the ongoing response operations, formulation of objectives, planning, and so on. Distribution of tasks, allocation of resources, and coordination of activities are other examples.
- The *operational C^2 level* is the lowest level where execution and coordination of actions and countermeasures take place. Thus it concerns the shortest time scales.

II) A number of models describing C^2 levels can be found in the military domain, the emergency and crisis management, and the process industry. These models are commonly three level models, and are in most cases almost identical. Though, there is a great variation how the different levels in the models are termed, which leads sometimes to confusion. For example, the process industry uses the following order of the C^2 levels: strategic, tactical and operational (Schmidt and Wilhelm, 2000). The same model and terms are also used in the British emergency management (UK CCS, 2007). The Swedish fire and rescue services use instead a four level model with the following C^2 levels: normative, strategic, operational and unit-based (Fredholm, 1997; Cedergårdh and Wennström, 2002). On the other hand, in the military domain the C^2 levels are recognized as strategic, operational and tactical (Lagerlöf and Pallin, 1999; Atkinson and Moffat, 2007; US DoA, 2008).

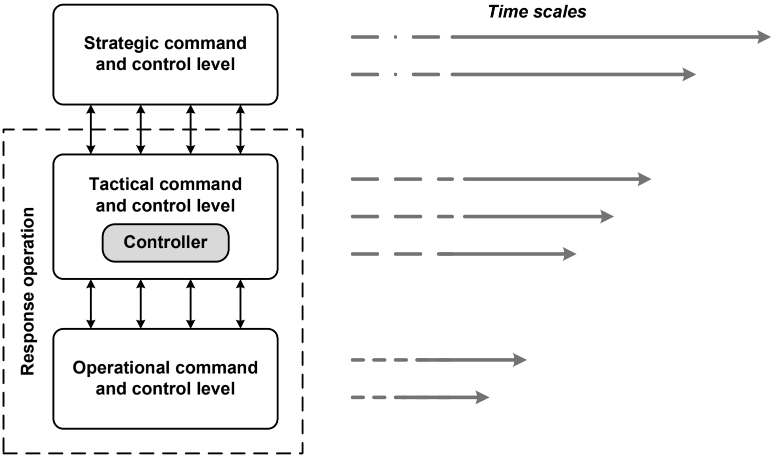

Figure 4: A model describing different command and control levels, which distinguishes command and control work on different time scales in a command and control system.

Controller as an adaptive structure

The fact that the controllers in response operations exist on temporary basis has an impact on (a) the characteristics of the controllers in terms of the initial conditions, as well as on (b) the context and constraints under which the controllers act. This can be demonstrated when the emergency and crisis management domain is compared with two other domains, where the dynamic control view and diverse C^2 concepts are often used, i.e., process industry and the military.

In the process industry such as transportation and energy distribution, the controllers and C^2 systems are permanently present, for example, a control room of an underground line (Garbis, 2002). The C^2 systems utilize top-down C^2 structures, and the controllers have explicitly specified structures, as well as defined positions and roles in the C^2 systems. The controllers and their C^2 capacity are dimensioned based on planning.

In the military, on the other hand, both the controllers and C^2 systems exist on temporary basis. They are initiated when necessary, i.e., for the purposes of military operations. The initiation period often stretches over a period of months (with the exception of air defense) and includes planning (e.g., Allard, 2002; Wentz, 2002; Lowry, 2008). When in place the military controllers and C^2 systems coexist in parallel until they are disbanded. The C^2 systems utilize top-down C^2 structures, and the controllers often have explicitly specified structures, as well as well-defined positions and roles in the C^2 systems. The dimension of the controllers and their C^2 capacity are largely based on planning.

In emergency and crisis management the C^2 systems exist permanently, but the controllers are transient. The controllers are initiated within minutes or hours after harmful events such as emergency or crisis, take place, and that on reactive basis. The controllers in the response operations exist only during the period of the operations. When the operations are concluded the controllers are disbanded. The controllers exist only during short periods of time compared to the other two domains (Figure 5). The controllers in the process industry and the military domain also have more explicitly defined structures, rules and relations than in emergency and crisis management. They also enter the control situations with preplanned and fully operational controllers.

In emergency and crisis management, the controllers are dimensioned and have C^2 capacity primarily based on actual needs in each response operation specifically (Svensson et al., 2005; Cedergårdh and Winnberg, 2006). The controllers are organized from nearest available parts and resources of the C^2 systems, that is humans and technological artifacts. Moreover, the controllers are configured during the initial stages of the response operations, while they must already carry out C^2 work and coordinate ongoing response efforts (Bigley and Roberts, 2001; Svensson et al., 2005). As a result, the controllers and their C^2 work in the response operations become qualitatively different compared to the process industry and the military domain in terms of how and in what way the controllers are initiated and set up.

The nature of the response operations may alter as a result of the situation in the area of operations, and available and deployed resources. The goals of the controllers may change several times during a single response operation (Bigley and Roberts, 2001; Svensson et al., 2005). This means that the type and number/volume of deployed resources may be continuously changing. The controllers must continuously adapt to these changes in terms of their form to match the variety of the resources during the entire response operation. This corresponds to the cybernetic law of requisite variety (Ashby, 1956) (Figure 6).

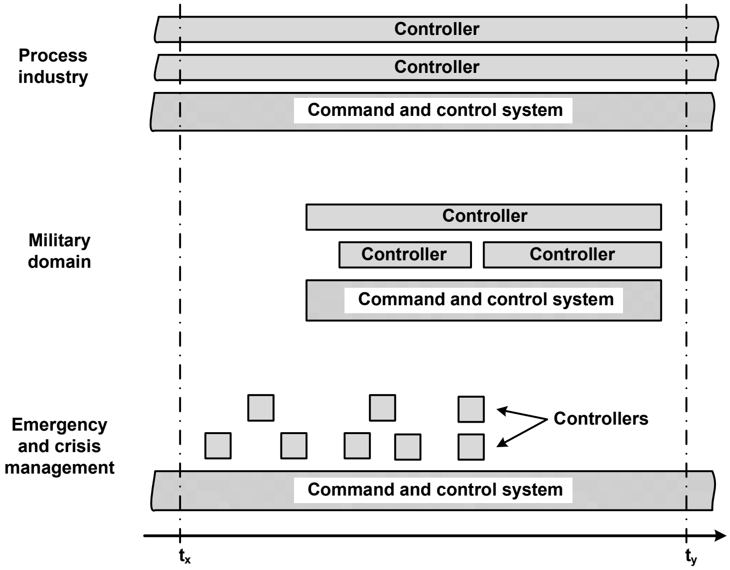

Figure 5: A comparison of controllers, C^2 systems and their temporal existence in the process industry, the emergency and crisis management and the military domain.

This continuous adaptation includes, for instance, the number of humans involved, their expertise and skills, the artifacts they use, and the internal configuration of the controllers. These changes are also equated with the shifting nature and number of relations and interactions within the controllers, as well as between the controllers and C^2 systems, which the controllers are a part of. The changes may include adaptations to the communication, and reallocation of the authority as well. As a result the controllers in the response operations have to, in most cases, cope with a greater variety than controllers working in the process industry and the military domain.

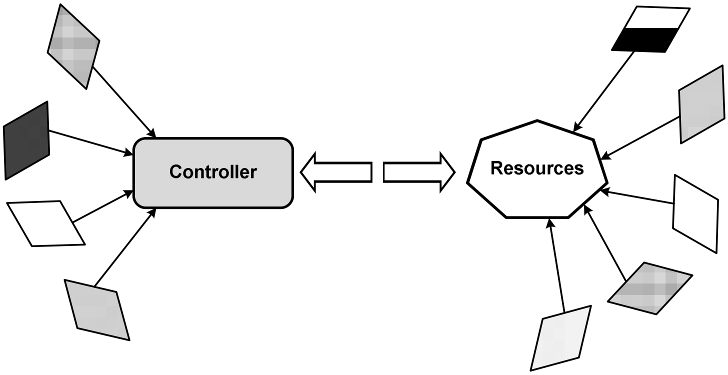

Figure 6: The way a controller is formed, and what/who is a part of the controller, depends besides other things on the available and deployed resources in the area of operations. The controller continuously adjusts to the number and type of resources deployed, that is the controller tries to adjust its control capacity in accordance with the law of requisite variety (Ashby, 1956).

2.2.2 Ways and forms of command and control work

Controllers of response operations often need to implement multiple countermeasures to achieve their goals. Which countermeasures are chosen and how they are combined rarely takes place on an *ad-hoc* basis but is commonly based on tactics. *Tactics* are combinations of countermeasures into various patterns, based on available resources and methods, to obtain the best possible outcome within the persisting time- and resource-constraints (Fredholm, 1991; Persson, 2000; Svensson, 2002). To effectively implement tactics, deploy resources and keep flexibility during response operations, diverse organizational and temporary configurations of the C^2 work within the tactical C^2 level, and between the tactical and operational C^2 level need to be utilized (Johansson, 2000; Bigley and Roberts, 2001; Cedergårdh and Winnberg, 2006). The organizational configurations concern: (a) what C^2 strategies are used to effectively deploy the resources, (b) in which way the C^2 work is arranged to effectively coordinate the countermeasures and actions put in place, and (c) how the C^2 work is organized in order to maintain control of the deployed resources and activities taking place. The temporary configurations correspond to when and in what way the controllers alter between the different C^2 strategies, structures and arrangements (Fredholm, 1997; Johansson, 2000, 2007; Svensson et al., 2005; Cedergårdh and Winnberg, 2006).

Command and control strategies

C^2 strategies relate to how and in what way the tactics are implemented, resources are led and coordinated, as well as how feedback on actions and countermeasures is collected. In the literature (e.g., Keithly and Ferris, 1999; Lagerlöf and Pallin, 1999; Zetterling, 1999; Johansson, 2000; Persson, 2000; Alberts et al., 2001; Widder, 2002; Kaiser et al, 2004) three main C^2 strategies can be found. These three strategies are: order specific, mission specific and autonomous strategy.

The *order specific* C^2 strategy is sometimes described as "leading by order" as it is based on detailed and specific instructions and orders to the operational C^2 level on "what should be done, how and when". Order specific C^2 also requires detailed and frequent feedback on the activities taking place at the operational level. This type of C^2 strategy is recognized as coordination and communication intensive. Order specific strategy is often utilized, for example, in C^2 of airborne operations (Persson, 2000).

The *mission specific* C^2 strategy is characterized by general instructions given to the operational C^2 level on "what should be done or achieved". This type of strategy can be described as "leading by task", in contrast to the order specific C^2 strategy. The instructions to the operational C^2 level take the form of directives, which include intentions, goals, deadlines, and some guidance toward identified objectives and potential problems. The mission specific strategy requires that the operational C^2 level is capable to take initiative, and choose appropriate actions and countermeasures. This type of strategy is used, for instance, by the Swedish fire and rescue services (Svensson et al., 2005).

The *autonomous* C^2 strategy means that the tactical C^2 level is only concerned with general objectives such as "save lives". The operational C^2 level and deployed resources use self-synchronization principles to choose and implement actions and countermeasures. The tactical C^2 level only supervises the ongoing activities. This type of strategy utilizes high flexibility and adaptability. An example of C^2 systems and resources applying this type of strategy is the Israeli emergency medical services and the voluntary organization "Hatzolah", employing autonomous C^2 in the initial stages of their response operations (Kaiser et al., 2004).

The different C^2 strategies require various competences, skills and capacities. The choice of C^2 strategy thus depends on a given situation, but also on skills, competence, and experience of the tactical and operational C^2 level, as well as on training, skills and capacities of deployed and available resources. There are also qualitative and quantitative differences between these three C^2 strategies (Table 1), which do not make the strategies equally applicable to all situations. The mission specific and autonomous C^2 strategy may not be suitable for all circumstances, for instance, where activities taking place are interrelated and/or restrained by the same type of constraints.

Table 1: A comparison of the three different command and control strategies with respect to feedback, command and resource attributes (a modification of the work by Alberts et al., 2001).

COMMAND AND CONTROL STRATEGIES	**Feedback attributes**		**Command attributes**		**Resource attributes**	
	Level of detail	**Frequency**	**Level of detail**	**Frequency**	**Competence / skills**	**Creativity / initiative**
Autonomous	*low*	*low*	*low*	*low*	*very high*	*very high*
Mission specific	*moderate*	*moderate*	*moderate / high*	*moderate / high*	*moderate / high*	*moderate / high*
Order specific	*high*	*very high*	*moderate*	*high*	*moderate / low*	*moderate / low*

Arrangements of command and control

Arrangements of C^2 concern how C^2 is structured with respect to the operational C^2 level, the resources and the area of operations. It aims to achieve *unity of direction* in the C^2 work (Johansson, 2000). In principle, there are three basic approaches to the arrangements of C^2 (Johansson, 2000; Brunacini, 2002; Kaiser et al., 2004; Walsh et al., 2005): geography-, function- and domain-based arrangements (Figure 7).

In the *geography-based arrangements* activities at the operational C^2 level are disposed according to the geography. In other words, the deployed resources allocated at each geographical sector should contain the functions and domains necessary to accomplish the goals related to the sectors.

In the *function-based arrangements* resources are allocated to support the specific functions or activities such as pumping, search and rescue, and evacuations, throughout the entire area of operations.

The *domain-based arrangements* organize resources based on the actors' domain of competence, for example, police forces, emergency medical services, and fire and rescue services, over the entire area of operations.

In reality, the different types of C^2 arrangements are often combined in various ways. For instance, the domain-based arrangements, i.e., fire and rescue, emergency medical services, police, could be used to structure the overall coordination of all resources in the area of operations. The function-based arrangements can then be used within each domain, e.g., surveillance, patrolling and transports within the police forces. Moreover, controllers may alter between the different C^2 arrangements during the response operations, similarly to the case of C^2 strategies (e.g., Bigley and Roberts, 2001; Andersson et al., 2004).

Span-of-control

Span-of-control is related to how C^2 work is organized to maintain control of the deployed resources and to prompt the activities taking place in the area of operations. Span-of-control takes into account human limitations in control. It concerns the number and range of activities and resources humans are capable to coordinate (Figure 8). Span-of-control is associated to the skills and competences of each individual as well as to the overall capacity of the controllers. Span-of-control is context-dependent, and is influenced by both, the chosen C^2 strategy as well as the arrangements of C^2. For instance, the order specific C^2 strategy has higher requirements on the coordination of resources and activities, and reduces thus the possible span-of-control compared to the mission specific C^2 strategy (Johansson, 2000; Cedergårdh and Winnberg, 2006).

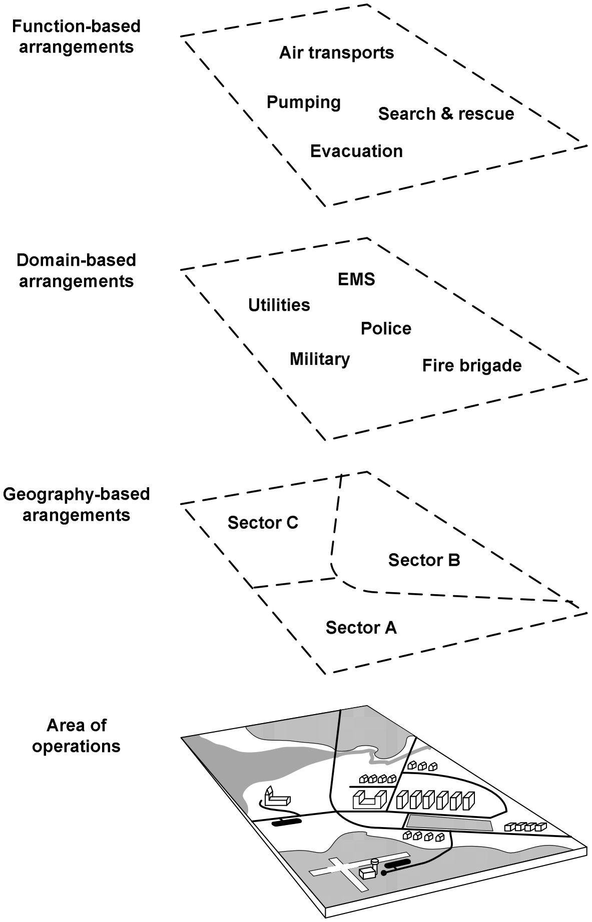

Figure 7: The different types of command and control arrangements in relation to the area of operations: function-based (top), domain-based (middle), and geography-based (bottom) arrangements.

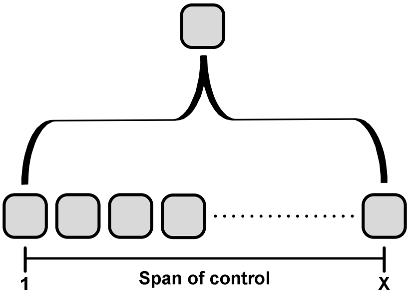

Figure 8: Span-of-control (adapted from Svensson et al., 2005)

2.2.3 Communication modeling

Communication represents a complex, pervasive and vital aspect of human activities (Littlejohn, 2002). Communication is also an essential element of C^2 work. No single theory can address all aspects of communication (ibid.). Many scientific perspectives on communication, its meaning and role can be found. Examples of such perspectives are communication as a social action (Haslett, 1987), communication as use of language (Clark, 1996; Akmajian et al., 2001), and communication as exchange of semiotic symbols (Pierce, 1958; Leeds-Hurwitz, 1993). In the context of this research, which aims to model C^2 work in response operations, communication can be described based on two constructs, which are close to the systems view:

- Communication as a systemic process,
- Communication as an infrastructure of a system.

Communication as a systemic process

The first construct conceptualizes communication from a dynamic perspective, that is as a systemic process. The communication is represented by a spatio-temporal distribution and connectivity of communicative acts. A communicative act occurs when a data-output from one system component becomes a data-input to another. This construct originates in cybernetics and represents the interaction approach to communication (Shannon and Weaver, 1949; Ashby, 1956), unveiling the dynamics of the studied systems (Mabry, 1999; Heath and Bryant, 2000; Jentsch and Bowers, 2005). The construct of communication as a systemic process corresponds to the patterns of interactions, and the distribution of information in the C² approach space introduced in this chapter. To describe communication according to this construct, the communication processes must be observable and have already taken place (Mabry, 1999). This way of communication modeling has also been used to document and describe communication in the emergency and crisis management domain (e.g., Petrescu-Prahova and Butts, 2005; Houghton et al., 2006; Landgren and Nuldén, 2007; Uhr, 2007).

Communication as a system infrastructure

This construct conceives communication from a structural perspective, describing communication as an infrastructure property of a system, which makes data exchange possible. This construct builds upon the transmission approach to communication, described by Shannon and Weaver (1949). This construct of communication allows to model systems where the specific communication has already taken place, but also prior to this communication. Even in this case the communication must be observable (Mabry, 1999).

Several authors such as Coakley (1992), Friman and Derefeldt (2004), Johansson (2005), and Johansson and Hollnagel (2007), have further elaborated the communication infrastructure construct by describing it as a concept embedded in a socio-technical context. In this concept, the communication infrastructure includes, for the purposes of analysis, three interdependent systems: organizational, social, and technical (Figure 9):

- The *social system* contains humans that are part of the controller and C² system. It concerns relationships that can be associated to inter-human, group, and informal arrangements.
- The *organizational system* is the formal organization of the controller and C² system. It includes formal channels of the organizational communication.
- The *technical system* refers to the technology such as hardware and software, connected through physical and wireless communication channels allowing exchange and sharing of data over space and time.

Ideally, these three systems should be interwoven. Though, it is important to be aware that their dynamics, meaning the rate and magnitude of change, are different. The properties of these systems depend, besides others, on context and constraints, as well as interactions that take place between the involved humans and organizations. If the properties of the systems in the communication infrastructure differ greatly, this can be seen as potential indicators of disturbed communication leading to conflicts among the humans and organizations involved. Several authors such as Rochlin and Demchak (1991), Rochlin (1999, 2000), Johansson (2005), Johansson and Hollnagel (2007), and Stanton et al. (2008), suggest that communication and consequently performance, ability to adapt, and control capacity of the controller are, besides others, influenced by the communication infrastructure.

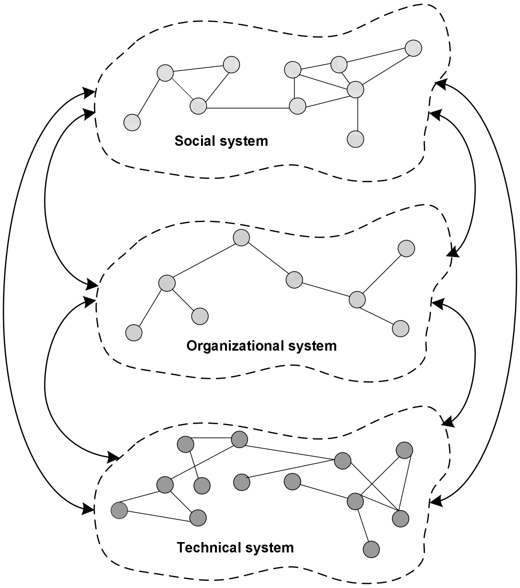

Figure 9: The social, organizational, and technical systems of a communication infrastructure (adapted from Johansson, 2005; Johansson and Hollnagel, 2007).

Artifacts supporting communication related activities

The types of artifacts this thesis focuses on are various designed artificial devices such as information systems and communication terminals that maintain, display and operate upon data to enhance human performance (Norman, 1991).

The kind of artifacts humans choose to use depends on the tasks they have to carry out. In other words, the choice is embedded in the dynamic context of human activities (Norman, 1991; Carroll and Rosson, 1992; Hutchins, 2001; Hollnagel and Woods, 2005). Norman (1991) suggests the human action cycle-model in order to understand the issues related to the use of artifacts as well as the interactions between the humans and artifacts. This model is coherent with the notion of control models described in this chapter. A similar notion, building upon a cyclic control model, is suggested by Hollnagel and Woods (2005).

The use of specific artifacts is influenced by different types of constraints (Miller and Woods, 1997). These constraints concern (Miller and Woods, 1997; Hutchins, 2001; Hollnagel and Woods, 2005):

- Constraints related to the *nature of the domain*, that is the larger socio-cultural context, and the tasks that have to be performed.
- Constraints due to the *design of the artifacts*.
- Constraints due to the *humans in the setting*, that is the skills, interests and preferences of the humans using the artifacts.

In the context of C^2 work, the artifacts, which are of interest, are those supporting communication in terms of a collection of feedback from the operational C^2 level and the area of operations, and dissemination of decisions, orders and intent to the operational C^2 level. Other types of relevant artifacts are those supporting the different C^2 functions of the controller such as detection, situational assessment and planning (Brehmer, 2008).

2.3 Modeling and simulations

The terms model and simulation are widely used in many of scientific disciplines. It is therefore not surprising that they have also been given different meanings. In this work, a *model* is defined as a representation of some aspects of the reality. It captures conceptual properties and assumptions of various objects, e.g., a situation, system or other phenomena, in the real world (Klein, 1985; Hartmann, 1996; Crookall and Saunders, 1998). A *simulation* is an execution of a model, while providing a representation of the way in which the real world objects change as time progresses (Klein, 1988; Hartmann, 1996). In other words, simulations are grounded in models of objects, whose time evolutions are simulated (Hartman, 1996) (Figure 10). Both, models and simulations need to use simplified assumptions to make their dynamics tractable (Weirich, 2008).

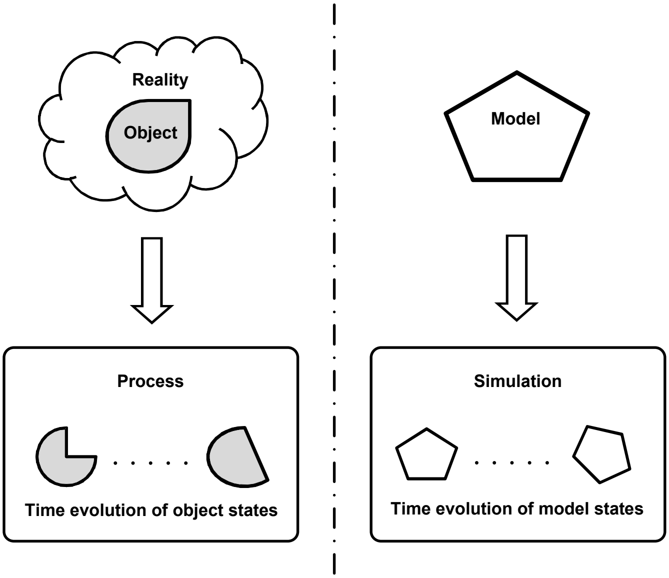

Figure 10: Relation between real objects and processes, and their models and simulations.

This research concerns role-playing simulations that aim to create conditions and events similar to the C^2 work in real response operations, that is to stimulate the simulation participants to make decisions, take actions and interact with others in that context. In general, when people take part in simulations, they indirectly interact with the models, modifying them and their variables (Niemeyer, 2003; Brynielsson, 2006). This process proceeds into more complex situations as the interactions go on among the participants during the simulations. The simulation participants' actions and behavior are influenced as well as dependent on the other participants, which may lead to both planned and unplanned variations of the simulation (Crano and Brewer, 2002). The interactions and interdependencies among the participants' actions and behavior result in internal parameters governing the simulations (Gestrelius, 1998). Moreover, if the participants act in simulations in their professional roles, they use their tacit knowledge, for example, to generate prospective choices, alternative courses of action, or contingency plans. This further increases the variations of the simulations (Cooper et al., 1980; Crookall et al., 1987; Bracken and Shubik, 2001).

Thus the modeling and simulation design of complex objects, especially when people acting in their professional roles are involved, requires attention. Winsberg (1999) highlights that it is a non-trivial process to bring a theoretical structure into resonance with complex objects. Even if good and well-understood theories and concepts, describing the objects in the real world, exist, the actual objects are often not sufficiently well understood because of the complexity and interactions involved in generating them. Researchers addressing the conceptual aspects of modeling and simulation design (e.g. Crookall et al, 1987; Hartmann, 1996; Winsberg, 1999; Silvert, 2001) argue that simulations of complex objects may require a complete hierarchy of models in order to link the theories and concepts to the studied objects. This is necessary in order to identify critical parameters and aspects of the objects, and to understand their underlying dynamics.

2.3.1 Model hierarchies

The goal of model hierarchies is to link diverse theories and concepts to the studied objects in a comprehensive way. Hartmann (1996) and Winsberg (1999) describe such model hierarchies as a process of combining models and theories. They, both focus on computer-based simulations, and use terms from computer science, contrary to this work. The model hierarchy described in this section uses general terms instead, and aggregates of some of the steps in the process.

The model hierarchy (Figure 11) contains three levels of models: (a) general models and concepts, (b) case specific models, and (c) simulation design.

General models and concepts provide universal assumptions and properties related to the type of studied objects. General models and concepts are not about specific objects in the real world. This level aims at conceptual and simplified descriptions that serve as a base for selection of features to be modeled into the forthcoming two levels (Crookall et al., 1987; Hartmann, 1996; Winsberg, 1999). The type of models and concepts considered at this level of the model hierarchy are, for instance, those described in chapter 2.1.

Case specific models are used to identify key parameters, boundary values, and initial conditions of the studied objects. Case specific models provide symbolic descriptions of specific objects. These models make the descriptions from the general models and concepts level applicable to these specific objects (Crookall et al., 1987; Hartmann, 1996; Crookall and Saunders, 1998;

Winsberg, 1999, 2001). Examples of the case specific models are models, concepts and assumptions presented in chapter 2.2.

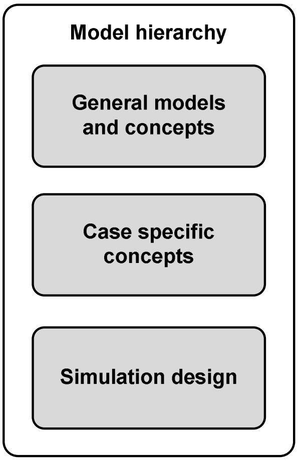

Figure 11: Model hierarchy (adapted from Hartmann, 1996; and Winsberg, 1999).

Simulation design leads to the final models, which are executed during the simulation. Simulation design covers three major areas: specification of relevant scenarios, compilation of high resolution models of C^2 work and response operations grounded in the scenarios, and transformation of the models and scenarios into a simulation ready form. The aim of these final models is to resemble the specific objects in the real world. They have thus a high resolution, are very specific, and include frameworks describing the specific patterns of the simulation and assumptions of how the simulation may evolve over time (Crookall et al., 1987; Hartmann, 1996; Crookall and Saunders, 1998; Winsberg, 1999; Achterbergh and Vriens, 2007).

2.3.2 *Scenario development*

Scenarios are in principle high resolution descriptions of reality that aim to provide an appropriate context for, and to identify the essential elements in, the simulation participants' decision problems (Klein, 1985; Parson, 1996). To achieve this goal, scenarios must have an appropriate richness, and they must reflect historical, social and other real life settings (Drabek and Haas, 1967; Parson, 1996; Yardley-Matwiejczuk, 1997).

The scenario development includes defining and modeling of objects and events that make up the base of the simulation content (Kleiboer, 1997). The scenario development takes into account the scope of the simulation, the relevant context, and the participants involved (Parson, 1996). An example of questions and topics that the scenario development commonly addresses is (a) the number and range of objectives, (b) the timescale and scenario duration, (c) the nature of required response, and (d) the number of roles, affecting the degree of interaction among the participants (Alexander, 2000). The process of scenario development leads to (Yardley-Matwiejczuk, 1997; Achterbergh and Vriens, 2007):

- Detailed models of the studied systems (e.g., C^2 system, controller and resources),
- Statements of the assumptions about the systems' operating environment (e.g., situations, incidents and constraints),
- Frameworks describing specific sequences of the systems' behavior, and
- Scripts of how the simulation may evolve over time.

The modeling of specific C^2 systems, controllers and resources include (1) possible size and structure of the controller, (2) ways and forms of C^2 work that the controller may apply, (3) range, type and frequency of interactions between the C^2 levels, (4) available resources and their characteristics, (5) commonly deployed tactics of the controller and resources, and (6) mapping of the communication infrastructure. The modeling also concerns work-related factors such as culture, norms, leadership and stress (e.g., Svensson et al., 2005; Larsson, 2005, 2006; Lindgren, 2007).

The assumptions about the actual area of operations, situations, incidents and other relevant constraints are commonly based on typical and recurrent situations and events taking place in real response operations (Kleiboer, 1997). At the same time, these assumptions need to be combined with new and unusual types of incidents for the participants to experience the scenario as realistic without being overly constrained or biased by their experiences from the actual response operations (Alexander, 2000). The assumptions have to be representative for the actual types of harmful events. Their degree of predictability should vary in order to stimulate the participants' thinking about the unexpected, that is creatively anticipating what could go wrong (Adamski and Westrum, 2003). Realistic, challenging and detailed assumptions may encourage foresight and anticipation of potential problems by the participants (Woltjer et al., 2006b).

2.3.3 Realism and its evaluation

The main challenge of the type of simulations, this thesis concerns, is to achieve that the participants behave in the simulation in a similar way to what they would have in real situations (Klein, 1985; Parson, 1996). A high *subjective realism* of the simulation is necessary in order to emerge behavior that is similar to the behavior the participants would demonstrate in reality. The simulation participants have to be put into an appropriate context and interact with appropriate models of the C^2 work and response operations. If the context and models do not match the real world situation, which is simulated, the participants may create an incorrect construct of the situation than intended by the simulation designers. As a result, the simulation participants may act upon this incorrect construct and use different theoretical and practical concepts than they would have done in the same situation in the reality (Klein, 1985; Parson, 1996). Thus the issue of simulation realism and its evaluation represents an essential part of simulations (Rolfe, 1991; Rubel, 2001; Achterbergh and Vriens, 2007).

Subjective realism

Subjective realism concerns the way the participants perceive the simulation (Parson, 1996; Crookall and Saunders, 1998; Alessi, 2000). Drabek and Haas (1967) describe five main areas of realism: groups, tasks, environment, social structures, and knowledge of participation. These five areas of realism influence: (a) if the participants perceive the simulation as realistic, and (b) if the participants act and behave in the simulation in a realistic way.

The *groups* equal to use of meaningful units of analysis represented by real groups of personnel with shared experience as participants. The *tasks* mean that the type of tasks, activities and demands, which the participants carry out in the simulation, is identical to the participants' sphere of tasks in the reality. The *environment* corresponds to the ecological settings in which the participants act, and which are same or very similar to the reality. The *social structures* mean that social systems are utilized so the interaction and relations between the participants are carried out in a realistic way. The *knowledge of participation* implies that the simulation participants are unaware of their participation in the simulation.

Parson (1996), Crookall and Saunders (1998), and Gestrelius (1998) highlight a *realistic feedback* on the participants' actions, both in terms of its form and content, as important to achieve a realistic behavior. This is, however, challenged by the fact that crisis and emergency response scenarios involve unique and novel problems. This type of simulations may thus require a combination of experts with domain-knowledge, formal models as well as detailed analysis and planning. This is necessary in order to determine and replicate effects and consequences of the participants' decisions and actions (Parson, 1996).

Realism relative simulation objectives

The main factor influencing the required level of realism in the simulation is the simulation objectives (Gestrelius, 1998). Four main types of simulations with respect to the simulation objectives can be recognized: (a) to train, (b) to evaluate, (c) to gain insights and (d) to demonstrate. Simulations focusing on *training* are educational simulations. This type of simulation has a clear relation to the training and learning objectives as well as the simulation layout, and evaluation of the participants' behavior and performance. Simulations focusing on *evaluation* aim to assess the behavior or performance of individuals, teams and C^2 organizations. This type of simulation is used, for instance, to evaluate dimensioning and robustness of C^2 organizations. Another example of this type of simulation is the validation of preparedness and response plans. Simulations conducted by the objective to *gain insights* aim to replicate or reconstruct situations and processes, which took place in reality, in order to gain deeper knowledge of what happened. An example of such simulations is replays of alarm sequences at C^2 centers to analyze the measures taken by the operators including why they approached the concerned situations in particular ways. Simulations designed to *demonstrate* intend to explicate "best practice" to manage certain problems, or to show *pros* and *cons* of the different ways of approaching certain situations (e.g., Lardinois, 1989; Jenvald, 1999; Boin et al., 2004; Stanton et al., 2005; US GAO, 2007).

Simulations focusing on behavior related to the domain-specific skills and knowledge such as application of explicit doctrines, and utilization of specific tactics, require a higher level of realism than simulations centered at the domain-general skills and knowledge, for instance, leadership and team communication. Simulations focusing on detailed aspects of the domain-general skills and knowledge may in certain situations require a high level of realism as well (Klein, 1988; Alessi, 2000). The participants' skills, knowledge and simulation experience represent an important factor with respect to simulation realism. There are qualitative and quantitative differences in how experienced and inexperienced participants behave in simulations. For instance, inexperienced participants more often accept the simulation scenario as it is, compared to experienced participants, who use their own assumptions and concepts and in a way build own scenarios to a certain context (Cooper et a., 1980).

Evaluation techniques

The key parameter with respect to the evaluation of realism in this type of simulations is the subjective realism (e.g., Mihram, 1972; Fenstein and Cannon, 2002). In this context, the relevant evaluation techniques are self-reflection by participants, and evaluation made by experts (Parson, 1996). *Self-reflection by participants* has the form of different debriefing techniques such as an after-action-review, where the participants themselves can reflect upon their performance and judge the realism of their behavior in the simulation both in formal and in informal ways (Scott, 1983; Downs et al., 1987; Rankin et al., 1995; Gestrelius, 1998). *Evaluation made by experts* concerns direct and indirect observations of the simulation and participants' behavior. The evaluating experts act as complete observers during the simulation execution (Denzin, 1978; Burgess, 1984; Beaubien et al., 2005).

2.3.4 Simulation layout

A simulation layout concerns the transformation of the scenario-grounded high resolution models of C^2 work and response operations into a simulation ready form.

One aspect of the simulation layout is the choice of a simulation format. There are in general four main simulation formats suitable for generating situations, where real commanding personnel operates in simulated real world systems, make decisions and act upon hypothetical conditions: (1) tactical decision games, (2) operational games, (3) functional exercises and (4) full-scale exercises. See Table 2 for a summary of the main properties of these four simulation formats. *Tactical decision games* are low-fidelity simulations using mental and visual simulation techniques, which focus on non-technical skills of the simulation participants (e.g., Schmitt, 1994; Klein, 1997, 1999; Crichton et al., 2000; Crichton and Flin, 2001). *Operational games* are simulations combining mental, visual and physical simulation techniques. Operational games aim at providing insights in decision-making in complex situations. They can have various levels of fidelity depending on the scope of the simulation (e.g., Shubik, 1972; Cooper, 1979; Klein and Cooper, 1982; Thomas, 1984; Rubel, 2001). *Functional exercises* are high-fidelity simulations combining mental, visual and physical simulation techniques. They focus on specific operational activities or command posts. They can be executed both indoor and in the field (e.g., Peterson and Perry, 1999; Payne, 1999; Green, 2004; US FEMA, 2007). *Full-scale exercises* are high-fidelity simulations that simulate most or all the functions, which may be involved in a real response operation. They are therefore always at least partly located outdoor (e.g., Peterson and Perry, 1999; Green, 2000; Perry, 2004; US FEMA, 2007).

Table 2: Some of the central properties of the four main simulation formats used in the emergency and crisis management domains (compiled from Cooper, 1979; Thomas, 1984; Gestrelius, 1998; Klein, 1999; Peterson and Perry, 1999; Green, 2000; Crano and Brewer, 2002; Perry, 2004).

SIMULATION FORMATS	**Simulation technique**	**Behavior form**	**Realism**	**Abstraction**	**Tempo**	**Duration**
Tactical decision game	***mental, visual***	***passive***	***low***	***High***	***higher than in reality***	***<1 hour***
Operational game	***mental, visual, physical***	***active***	***low / moderate***	***varying***	***often higher than in reality***	***1-4 hours***
Functional exercise	***mental, visual, physical***	***active***	***moderate / high***	***moderate / high***	***same as in reality***	***1-8 hours***
Full-scale exercise	***mental, visual, physical***	***active***	***high***	***moderate / high***	***same as in reality***	***3 hours - 10 days***

The level of control in the simulation is another aspect of the simulation layout that has an influence on the various simulation features and settings such as the task and content fidelity and simulation complexity. The level of control concerns the simulation managers' control over the scheduling of simulation stimuli during the simulation (Adelman, 1991). In general two levels of control can be distinguished, i.e., high- and low-level control simulations.

The *high-level control* simulations often have research questions in the form of hypotheses, and are frequently carried out as comparative and experimental studies. The data collection focuses mainly on quantitative data in order to analyze in-depth what interactions took place. These simulations are in many cases faster than normal time, use predefined scenarios, and evaluate assumed technological capabilities. Examples of high-level control simulations are microworld studies (e.g., Artman and Granlund, 1998; Granlund, 2004; Gonzales et al., 2005) and some operational games (e.g., Kraus et al., 1999; Beroggi et al., 2001; Mendonça et al., 2003; Gu and Mendonça, 2005).

Compared to the high-level control simulations, the *low-level control* simulations have the form of case studies and quasi-experiments (Adelman, 1991). The focus of the data collection and analysis is different as well. The attention is given primarily to qualitative data and analysis of how the different interactions and processes took place. The low-level control simulations are characterized by the high-level task, content and environmental fidelity, and the use of progressively unfolding scenarios. The pace of these simulations is the same as normal time. The artifacts studied in these types of simulations are often real tools or their high-fidelity prototypes. Examples of low-level control simulations are crisis and emergency management exercises (e.g., Artman and Persson, 2000; Woltjer et al., 2006a; Mackenzie et al., 2007).

The last aspect of the simulation layout is the type of simulation control. The *type of simulation control* concerns in what way and by whom the simulation execution is managed and controlled. The type of simulation control also influences, besides others, transparency and complexity of the simulations (Bracken and Shubik, 2001). It is closely related to the level of control in the simulation. The simulation control can range from being entirely automated as in computer-based simulations (e.g., microworlds), to entirely human as in some role-playing games (Klein, 1985; Kleiboer, 1997). Various examples of semi-automatic and computer-assisted simulation control can be found as well (Jenvald, 1999; Morin, 2002; Jenvald and Morin, 2004).

The simulation format, level of control in the simulation, and type of simulation control are the main aspects of the simulation layout that influence the final simulation form. They are often combined in numerous ways in order to meet the demands with respect to the scope of the simulations and the required realism. But they also take into account the practical and pragmatic issues such as tractability and data collection.

SUMMARY OF STUDIES

This chapter reviews role-playing simulations of C^2 work, conducted as a part of this research, and the main findings from these simulations. The utilized simulation approach is scenario-based real-time role-playing simulations grounded in models of C^2 work and response operations. Three simulations have been conducted based on this methodology and are reported in this thesis. The simulations are: ALFA-05, GNEX-06 and EX-2008.

ALFA-05 gave attention to the C^2 work of the commanders from the Swedish local and regional emergency management organizations responding to a forest fire scenario (Paper I and II).

GNEX-06 focused on the issue of operationalizing earth observation technologies performed by the prospective European expert teams for rapid crisis response. The scenario was a release of radioactive noble gases from an accident at a nuclear power plant (Paper III).

EX-2008 aimed at gaining insights in the C^2 work of the command staff of the Swedish Response Team, dispatched to carry out an international response operation. The scenario was a forest fire with related large scale evacuations (Paper IV).

3.1 Methodology

This research is based on role-playing simulations as methodological means for qualitative research. Role-playing simulations involve humans and are interactive multi-person settings where reality or parts of reality are reproduced (Crookall and Saunders, 1998). The simulations are scenario-based, and combine features of two simulation formats, i.e., operational games and functional exercises. The simulations utilize the low-level control and use humans to control their execution. The simulation models, settings and layout, which are the basis for executions of the simulations, are grounded in models of C^2 work and response operations.

The simulations are executed in real-time, that is the participants face tasks to be conducted in present time, and the development of the tasks can be described as dynamic (Brehmer, 1987). The participants are real decision-makers, commanders and operators making decisions on hypothetical conditions and operating simulated systems, which aim to place the participants in vivid, demanding and realistic situations (Parson, 1996; Skyttner, 2001). The participants are enforced to act under uncertainty and time pressure, when having access to limited resources and information. They also need to use skills and knowledge, which are domain-specific as well as domain-general in order to accomplish their tasks.

Figure 12 provides a schematic example on how the conducted simulations were organized. Table 3 and Figure 13 describe the key characteristics of the conducted simulations. Table 4 gives an overview of the included papers and their focus.

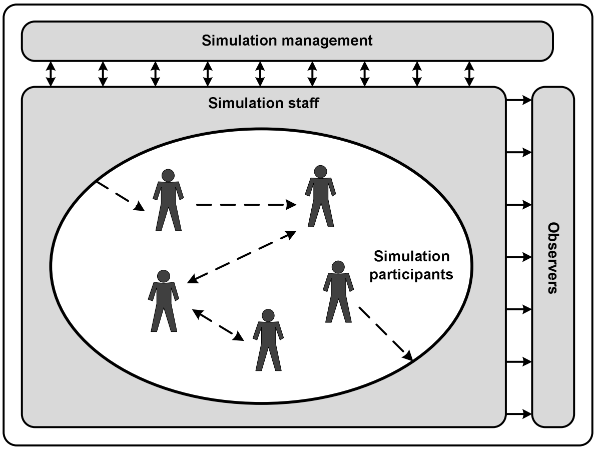

Figure 12: A schematic example on how a scenario-based real-time role-playing simulation is organized: simulation participants, who interact with each other and with the simulation staff while observed by the observers.

Table 3: Overview of the conducted simulations (ALFA-05, GNEX-06 and EX-2008) and some of the key characteristics and facts of these simulations.

CONDUCTED SIMULATIONS	Simulation technique	Simulation objectives	Interactions in focus	Unfolding scenario	Validation	Number of participants	Duration
ALFA-05	*mental visual*	*- to gain insights in C^2 work*	*tactical - operational*	*Yes*	*self-reflection evaluation*	*7 persons*	*2 hours*
GNEX-06	*mental visual*	*- to gain insights in C^2 work - to investigate use of artifacts*	*strategic - tactical*	*No*	*self-reflection evaluation*	*64 persons (3 teams)*	*33 hours*
EX-2008	*mental visual physical*	*- to design a simulation - to gain insights in C^2 work*	*strategic - tactical - operational*	*Yes*	*self-reflection evaluation*	*11 persons*	*4,5 hours*

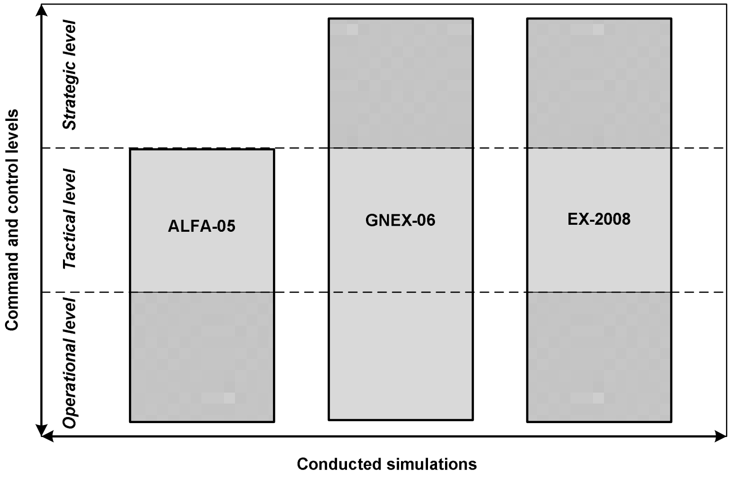

Figure 13: Conducted role-playing simulations (ALFA-05, GNEX-06 and EX-2008); the simulated C^2 activities in the C^2 level model, and the interactions taking place in the simulation between the different C^2 levels (░ activities and interactions initiated by the participants, and ▒ activities and interactions initiated by the simulation staff).

Table 4: Overview of the included paper and their focus.

INCLUDED PAPERS	Simulation	Focus
Paper I	***ALFA-05***	***- Simulation methodology***
Paper II	***ALFA-05***	***- Simulation methodology*** ***- Supporting the artifacts design***
Paper III	***GNEX-06***	***- Simulation methodology*** ***- Investigating the use of artifacts***
Paper IV	***EX-2008***	***- Simulation methodology***

3.2 Simulation I: ALFA-05

The first simulation, called ALFA-05, focused on the issue of design and development of C^2 tools to support collaborative work and processes in C^2 teams, where the team members may be distributed across different organizations. Information seeking, communication, and data sharing were given explicit attention as the essential elements of the collaborative C^2 work. The aim of the simulation was (1) to document the work practice of a team of commanders responding to an emergency situation, and (2) to identify the areas and activities, that may be enhanced by the use of technological artifacts.

The simulation was a scenario-based real-time role-playing simulation with seven participants. The participants were commanders from the emergency management services, e.g., fire and rescue, police, and emergency medical service, who lived and worked in the actual geographical area where the scenario and simulated events took place. All worked regularly at command posts corresponding to their assignments in the simulation. The scenario was based on a single self-contained event, which was represented by a forest fire. The scenario and its size were designed to involve emergency management organizations from two neighboring counties in a joint emergency response operation. The task concerned a response to a forest fire at the common border of the two different counties. The location of the forest fire aimed to trigger unclear operational procedures with regard to the C^2 responsibilities. Further, a number of additional incidents were selected in order to establish a certain context with respect to the objectives, and to control the tempo of the simulation. The simulation was initiated by multiple emergency calls and carried on for two hours.

The communication during the simulation represented the main data source. The participants were allowed to communicate between each other and with the simulation staff only through text messages. All communications were stored on log-files. The participants' workplaces were recorded by nine video cameras. All the material used by the participants in the simulation was archived. An after-action review was conducted right after the simulation. The collected data were analyzed by using a combined set of methods: episodic analysis, socio-metric status and communication classification/roles.

3.2.1 Main results

The results of the simulation suggest that the distribution of the communication density between the different command posts was not directly related to the scenario and its incidents, but rather to the availability of resources given to the particular commanders. The resource availability and allocation had impacts on the communication volume. The commanders communicated pro-actively, distributing information on a push-basis. The way information was searched, where and how, was dependent on the dynamics and the task load in the simulation. Information seeking was dependent on the local knowledge, experiences and task load (see Paper I).

Differences between planned and actual C^2 work were found. Tasks were distributed differently based on the situation rather than according to the organizational arrangements. The results indicate that the commanders used informal arrangements within the established C^2 structures. The commanders actively initiated diverse activities, and undertook various informal functions and different communication roles. These activities, functions and communication roles stretched across organizational and domain boundaries. Cross-domain and cross-organizational knowledge allowed the commanders from the different organizations to recognize the need for active engagement in diverse, joint activities and for supporting the other commanders. The analysis revealed that the existing C^2 tools, used by the participants at work in their organizations, did not provide any support with respect to conducting informal functions, indicating a current overview of functions and roles, or sharing "soft" information such as personal judgments and estimations. The design and development of methods and other aids to support this type of coordination should therefore receive attention in future C^2 tools (see Paper II).

Besides Paper I and II the simulation has resulted in three additional publications (Trnka et al., 2006; Woltjer et al, 2006b; Aminoff et al., 2007).

3.3 Simulation II: GNEX-06

The second simulation, called GNEX-06, was centered on the issue of observation technologies and their operational use in crisis response. This includes how they should be implemented to benefit from the possibilities they provide. It also includes to what extent they can meet the known demands of the crisis management with respect to contingency, adaptive capacity, and uncertainty. The simulation focused on expert teams providing remote support, in the form of analytical products and services based on earth observation data, to various decision-makers. The teams' tasks concerned work on digital satellite imagery such as data collection, fusion, analysis and visualization, that were accomplished by the aid of various computer-based tools. The simulation aimed to gain knowledge of operational deployment of earth observation technologies by expert teams in rapid response operations.

The simulation was a scenario-based real-time role-playing simulation. In the simulation, three expert teams worked in parallel on identical tasks related to rapid mapping tasks in a crisis response context. The type of teams and technologies that the simulation focused on were not initially in place or operational. This affected the way the teams were selected and prepared. The teams were temporary teams consisting of, on average, twenty-one members in each team. The team members were researchers and operators from thirty organizations participating in the "Network of Excellence on Global Monitoring for Security and Stability" (NoE GMOSS), who acted as prospective members of the expert teams in the simulation. The simulation was based on a single, self-contained event. This event was an incident in a nuclear power-plant followed by a release of radioactive noble gases. The teams' tasks were to provide detailed information on: (a) the current land-use in the contaminated areas, and (b) the changes in the industrial sites and urban areas. The tasks required a process chain from the data access to the visualization to be executed. The simulation duration was a priori set to thirty-three hours.

The main data collection technique was observations by experts. The observations were carried out in a semi-structured way. The observations focused on the use of earth observation technologies as well as on the team configuration, communication, coordination, task allocation and adaptive behavior. An after-action review was conducted immediately after the simulation was concluded. The teams' collaborative work and the outcomes delivered by the teams were evaluated by experts from the remote sensing, crisis management and nuclear safety domains. The simulation was also followed by two workshops within six months of the simulation.

3.3.1 Main results

The simulation provided an opportunity to study actual work and interaction emerging from the collaborative processes of deploying earth observation technologies during crisis responses. The simulation identified the opportunities and constraints emerging from the practical application of these technologies by expert response teams in a rapid crisis response.

An area in focus was the utilization of the various computer-based tools in the process chain. The teams used, in total nineteen, different tools to accomplish the same tasks. Ten tools were commercial-off-the-shelf and nine were in-house developed tools. On average, each team used nine tools. Three tools, all commercial-off-the-shelf, were used by all three teams. The different team configurations and the used means for communication did not seem to have any significant impact on the teams' choice of tools. Unfortunately, the use of the non-standard classification schemes and the vague quality and reliability statements, by all the three teams, did not allow any comparison of the delivered outcomes.

The analysis also revealed that the distributed team work and the related communication challenges led to problems with the task handover and the redundancy of the products in all the teams. All the three teams also experienced difficulties when operating under time-pressure. This resulted in the following behavior. First, the severe time-constraints caused non-standard land cover classifications to be used including cartographic visualizations. Second, the time pressure also resulted in insufficient quality management. Third, with the increasing time pressure, the teams tended to switch from advanced in-house developed tools to commercial-off-the-shelf tools. Forth, the teams were missing contingency plans even though the teams demonstrated good coping capabilities.

From the findings in this study, an area that requires further attention, is the expertise and skills available in this type of teams. The simulation revealed that, besides capabilities in the area of earth observation data analysis, data integration, visualization, and security concepts, the teams also need expertise in other general areas, for example, contingency planning and process planning, but also in specific areas with respect to the given scenario such as cartography and ecology. The team members need their specific technical skills, but in cases of crises it is absolutely necessary that they have additional “soft” skills in the field of management and communication. These skills seemed to be missing in this simulation (see Paper III and Voigt et al., 2009).

The simulation experience and its outcomes have been analyzed and reported in a number of publications by other authors (e.g., Beumier, 2007; Resch et al., 2007; Tiede and Lang, 2007; Lacroix et al., 2008; Mund et al., 2008).

3.4 Simulation III: EX-2008

The third simulation, called EX-2008, gave attention to the methodological issues of studying role improvisation. The simulation focused on C^2 teams designated for crisis and disaster response operations in an international context. The overall objective was to develop, on the bases of real response operations, a role-playing simulation to explore and study role improvisation in highly realistic situations. The study was based on a single-case, the command staff of the Swedish Response Team. The research included (a) identifying critical areas concerning role improvisation of the command staff, (b) proposing a model-based simulation design that incorporates these areas, and (c) preparing and executing a role-playing simulation based on this design.

The critical areas with respect to role improvisation were identified by means of qualitative analysis of two operations conducted by the Swedish Response Team, that is the 2004 Thailand and the 2006 Middle East operations. The analysis utilized a phenomenological approach, and was based on twenty-two interviews and three focus-groups. The analysis focused on if and what kind of role improvisation occurred in the studied operations. The identified critical areas were incorporated in the simulation design. This was based on a synthesis of the simulation approach, scenario and tasks, improvisation variables, and models of C^2 and response operations. The integration of the critical areas in the simulation design was achieved by means of the initial set-up, scenario stimuli, and interactions with the simulation staff. This design also included the use of information-injects ahead of the simulation. The developed simulation was a scenario-based real-time role-playing simulation with a progressively unfolding scenario. The scenario was based on events taking place during the 2007 California wildfires. The simulation participants were members of the command staff of the Swedish Response Team. The tasks of the command staff were (i) to take over a command post, (ii) to establish a functional command staff at this post, and (iii) to initiate activities according to the mission objectives.

The simulation resulted in a comprehensive set of data, containing (a) all voice and data communication from and to the command staff, (b) video recordings of the command staff's premises from four cameras, (c) material, data-files, notes and drawings used and created by the participants, (d) a large number of photos taken during the simulation, and (e) observations, documented in the form of notes. The collected data were structured by using the reconstruction and exploration approach.

The simulation was evaluated by assessing the subjective realism. The used evaluation technique was the self-reflection by participants, and had the form of an after-action review. The after-action review was complemented by a survey and a workshop.

3.4.1 Main results

Simulation III aimed to create conditions and events similar to real response operations, and to stimulate role improvisation. The analysis in the pre-simulation phase highlighted that flexibility and adaptability were common practice in the two studied response operations. This included the organizations of the missions, as well as how operations and tasks were carried out. The ability to take on a new role or to switch between different roles was identified as a prerequisite for a successful accomplishment of the tasks, and a significant practice to master. Three areas critical with respect to role improvisation were identified: (a) the coordination of expertise and skills upon arrival to the area of operations, (b) the performance of roles outside the team's field of competence, and (c) the management of improvised roles over time. The simulation design incorporated these three areas.

The evaluation pointed out that the simulation succeeded in terms of creating situations where role improvisation in the three identified critical areas was necessary and took place. First, the observers reported that the participants had been conducting activities, which were related to role improvisation in all the three areas. Second, the simulation staff initiated successfully all the stimuli concerning role improvisation in these areas. Third, the participants identified the critical areas and their role improvisation related to these areas as the main experience as an essential part of the scenario and the main experience from the simulation.

The evaluation focusing on how the participants perceived the simulation revealed that the participants assessed the simulation as realistic, especially the overall scenario and its events, and the feedback on the participants' actions in the simulation. Another feature that was in particular appreciated, adding realism to the simulation, was the information-injects. At the same time, the discussion during the after-action review showed that the participants may not always have the necessary frame of reference to compare the experience from the simulation with their real-life experience concerning their performance and behavior. This highlights the need for additional techniques to assess realism and consequently evaluate the simulations, especially when concerning improvised roles outside own/team's field of competence.

The evaluation focusing on the participants' actions and behavior in the simulation showed that the participants could assess their individual performance. But they asked for external assessment of their team behavior and performance. This concerned primarily feedback on the process of improvisation, but also its outcomes. It is, however, a challenge to assess if and why role improvisation worked or not. Some decisions and actions, which are the result of role improvisation, may lead to outcomes or have consequences outside the simulated time sequence. As a result, the participants as well as the simulation managers and staff may have difficulties to identify or estimate such outcomes and consequences during the simulation. The simulation showed that there is a need for additional and more advanced techniques to analyze role improvisation, its outcomes and potential consequences. Examples of such techniques are modeling and analysis of prospective effects of the participants' decisions and actions, and expert assessments of the outcomes of the improvised roles.

The experiences from the simulation suggest that it is feasible to study individual- as well as team- role improvisation in crisis and disaster response teams by this type of simulations. The proposed simulation design made it possible to utilize an advanced scenario and simulate dynamically developing situations and an already ongoing response operation, while allowing a comprehensive data collection. The simulation experience resulted in the identification of demands and requirements, which have to be met in order to simulate highly realistic situations. It also points out areas that require attention in order to use the role-playing simulations to explore and study role improvisation. These areas concern the need for additional and more advanced techniques (a) to assess the realism of participants' actions and behavior and evaluate the simulation, and (b) to analyze participants' role improvisations, their outcomes and potential consequences (see Paper IV).

Currently three additional publications (journal articles) are being prepared.

DISCUSSION AND CONCLUSIONS

To document and analyze C^2 work in dynamic and non-routine situations in a real-life context is a challenging methodological task. This thesis gives attention to scenario-based real-time role-playing simulations of tactical C^2. This chapter discusses the results and experiences from the conducted role-playing simulations with respect to the research questions and objectives.

4.1 The research objectives and the conducted studies

The objectives of this research were (a) to develop and execute role-playing simulations, which would allow to study C^2 work at the tactical level in the initial stages of response operations, (b) to assess if, how and to which extent role-playing simulations can be used to simulate C^2 work, and (c) to explore and analyze the C^2 work documented in the conducted role-playing simulations with respect to the research use as well as the design and development purposes. The objectives have been fulfilled by conducting three role-playing simulations focusing on the following topics:

- Addressing the methodological aspects of preparing and conducting role-playing simulations (Simulation I, II and III),
- Exploring adaptive C^2 work at the tactical C^2 level (Simulation I and III),
- Providing input for design of artifacts to support collaborative C^2 work (Simulation I),
- Investigating the use of artifacts in realistic settings (Simulation II),
- Developing a simulation to explore and study role improvisation in highly realistic situations (Simulation III).

Research objective I: "To develop and execute role-playing simulations, which would allow to study C^2 work at the tactical level in the initial stages of the response operations."

The conducted simulations aimed to meet the combined demands of the research in naturalistic settings and in the field of simulations. The simulations had to involve professionals and real groups. They also had to utilize tasks, activities, and demands similar or identical to the real ones. Moreover, the simulations had to allow the simulation participants to be adaptive and flexible, permitting different work modes as well as various organizational structures.

All three simulations fulfilled these demands. The conducted simulations were determined to study three different types of controllers in the context of three different types of response operations. They simulated C^2 situations where real decision-makers, commanders and operators acted in their professional roles and worked with tasks they commonly have worked on during real response operations. Simulation I (ALFA-05) gave attention to the commanders from the Swedish local and regional emergency management organizations responding jointly to a medium size forest fire. Simulation II (GNEX-06) focused on the prospective European expert teams supporting remotely response efforts to a nationwide crisis, concerning a release of radioactive noble gases from an accident at a nuclear power plant. Simulation III (EX-2008) aimed at the command staff of the Swedish Response Team dispatched to carry out an international operation as a response to extensive forest fires and related large scale evacuations.

The experiences from these simulations indicate that the chosen simulation approach, that is scenario-based real-time role-playing simulations, makes it feasible to simulate behavior of real controllers and C^2 systems. The methodology is applicable to controllers with different types of C^2 configurations and organizations. The methodology is also feasible to simulate adaptive C^2 work. For instance, it was possible to simulate different types of C^2 work such as scaling-up a C^2 organization in the initial stages of a joint response operation (Simulation I), and role improvisation in a command staff (Simulation III). The methodology also allowed simulations of different types of response operations ranging from regional emergencies to international missions.

The conducted simulations were evaluated by assessing the subjective realism. All three simulations were perceived as realistic by the participants, containing events and situations recognized from real response operations.

The participants also evaluated their own behavior and consequently the simulations as realistic (see Paper I, III and IV).

Research objective II: "To assess if, how and to which extent role-playing simulations can be used to simulate C^2 work."

The methodology provided a platform for realistic simulations of dynamic and non-routine events, which are challenging to document in real-life settings. That is, in this case, initial stages of emergency and crisis response operations. The conducted simulations allowed studying C^2 work in this type of operations in a way, which would otherwise be difficult to achieve by using other methodologies. It is in particular the possibility to conduct inquiries in a structured way, collect a wide range of high resolution data and create rich contextual descriptions. Moreover, situations envisaged in Simulation II and III would be unlikely or even impossible to study in any other way.

The experiences from the conducted simulations indicate that there are several methodological aspects that need to be considered in order to utilize the role-playing simulation approach.

First, the conducted simulations were developed and executed with different purposes and objectives. Simulation I and III aimed to gain insights in C^2 work, in particular when concerning adaptive behavior and improvisation. Simulation I was also centered on mapping work practice for design of artifacts to support collaborative C^2 work. Simulation II focused on evaluating the use of artifacts in C^2 teams. In other words, the role-playing simulation approach is feasible for explorative qualitative inquiries and evaluation studies of different problems domains. The role-playing simulation approach is also pertinent for training and demonstrations. But the methodology has not been used for this purpose in this research and it cannot be assessed to which extent it is feasible for it.

Second, the methodology made it possible to study behavior at the individual level as well as the overall behavior of the controllers. This includes information distribution and communication, collaborative processes, and complex decision-making. It also allowed to study in detail the actual interactions between the controllers and other parts of the C^2 systems as well as among the individuals who were a part of the controllers. This makes the methodology appropriate for situations where we need to find out whether and how certain activities, processes and interactions take place. However, the methodology itself cannot provide in-depth answers about why these activities, processes and interactions took place and what their causes were. The complexity of the simulated situations and events, and the context within which the different activities, processes and interactions take place require additional methods and techniques to obtain the answers. In this research, an after-action review was used, besides for evaluation purposes, to obtain participants' explanations and clarifications (Simulation I and III). Other types of methods and techniques relevant in this context are, for instance, interviews, field observations, and other types of simulations.

Third, attention is particularly required with respect to the balance between the research questions and the simulation complexity. The methodology facilitates complex situations and advanced realistic scenarios. Simulation I and III even utilized progressively unfolding and open-ended scenarios. This already requires coordination of extensive technological, organizational and human resources. On the average, the conducted simulations required eight to ten months of planning, diverse types of information and communication technologies to run and document the simulations, and approximately twenty simulation, support and observation personnel during the execution. The experiences from the simulations suggest that more intensive and complex scenarios may represent a major test for the simulation managers and staff. In particular, this concerns their ability (a) to gain an understanding of the simulation in progress, (b) to provide appropriate feedback to the participants on their actions in the simulation, (c) to manage the scheduling of simulation stimuli, and consequently (d) to execute the simulation successfully and achieve the objectives.

Fourth, certain considerations are necessary with respect to situations that the participants are exposed to in the simulations. The experiences from the conducted simulations show that certain situations are rather challenging to replicate in a realistic way. This is especially the case when simulating sequences with high communication load and the related stress, for example, in the form of multiple emergency calls or intensive media pressure. Not all situations can be sufficiently simulated and this should be taken into account when developing scenarios. Moreover, not all scenarios are equally suitable to be studied by this methodology. It is difficult to simulate situations where the participants have normally visual information over the area of operations and on the events and activities taking place there. The challenge is to produce this visual information and to replicate the participants' actions and their effects in this information. Examples of such scenarios are, for instance, industrial fires and building collapses.

Fifth, only single simulations were conducted. This means that the simulation layout and scenario were executed only once. This was due to practical reasons. Each simulation was a part of another project. Therefore the simulations cannot be assessed if they are repeatable in the sense that the set-up and scenarios are replicable. Moreover, the simulations had different objectives and focused on different types of controllers, C^2 systems and response operations. As a result, the conducted simulations were not compared. With this in mind, this research does not provide any enclosures with respect to how such simulations could be compared.

Finally, it is rather the type of a specific question or the nature of a problem under scrutiny that influence if, how and to which extent the methodology can be used. The role-playing simulation approach as any other methodology has its *pros* and *cons*, and is more suitable for certain types of problems and questions and less for others. The applicability of the methodology should therefore be assessed from case to case.

Research objective III: "To explore and analyze the C^2 work documented in the conducted role-playing simulations with respect to the research use as well as the design and development purposes."

The findings of this research show that improvisation and adaptation are essential elements of C^2 work. Paper II and IV highlight the importance of being able to adapt and improvise as well as how this can be done in practice. Paper III adds another perspective on this issue by showing the need for adaptive capacity even in highly technologically dependent C^2 team(-s) in order to perform tasks in response operations. The knowledge on how decision-makers, commanders and operators adapt and improvise in specific situations is not only relevant for research on, for example, teamwork and resilience, but also for design of training, or dimensioning of C^2 structures. This knowledge also represents an essential input for design and development of diverse technological artifacts and systems. For instance, Simulation I points out that artifacts designed and developed only on the basis of formal C^2 doctrines and task specifications may most likely inhibit parts of the collaborative work in joint response operations.

The conducted simulations, in particular Simulation II, also provided insights in utilization of advanced technological artifacts in complex processes. The artifacts used in Simulation II provided novel ways of conducting C^2 work, that is, in this case, situation assessment, planning and supporting operations. The results indicate that all artifacts that have been designed and developed for the use in crisis response do not meet the demands of response operations and cannot actually be used in reality under these circumstances and with the intended purposes. The methodology thus also represents a suitable tool to investigate utilization of artifacts, which are components of or connected to larger technological systems, and/or are used in a wider context of C^2 systems.

4.2 A general discussion of the research results

This thesis focused on role-playing simulations. Role-playing simulations were used in research as far back as in the sixties and seventies of the twentieth century (e.g. Babb et al., 1966; Shubik, 1972; Cooper, 1978). The "handicraft" of designing and executing role-playing simulations has been well-known as well. The methodology has also been recognized both in the military and the crisis management domain (e.g., Perla, 1990; Kleiboer, 1997; Rubel, 2001; Boin et al., 2004). The presented research represents a work that aims to further develop the use and extend the applicability of this methodology in the context of these two domains.

In this research, the methodology was used to simulate adaptive C^2 work at the tactical level in the initial stages of response operations. This includes situations when the most dynamic phases of emergencies and crises take place; situations when decision-makers and commanders decide upon actions and coordinate activities in an intense way; and situations where command posts are being or have just been established and the C^2 organizations are forming their structures. It is a challenge to document and study C^2 work under such circumstances. The presented research should therefore be seen as an attempt to fill in a methodological gap in studying this type of C^2 work.

The experience from the conducted simulations indicates that there are three main areas that need to be considered in order to further develop this methodology and its applicability, especially with respect to comparability and transferability of the simulations and their findings. These areas are: (a) models and model hierarchies, (b) evaluation, and (c) methods for analysis of context-bound data.

4.2.1 Models and model hierarchies

The conducted simulations revealed the need for coherent theoretical descriptions of C^2 and response operations in the form of model hierarchies in order to design, execute and analyze the simulations in a methodologically sound way. Research utilizing the experimental approach often builds upon single and general models and concepts. This also includes reducing or removing context, while having full control over the selected variables. Research in the form of field studies, on the other hand, uses case specific concepts, corresponding to high resolution context-bound models. The role-playing methodology, when used in the way as in the presented research, requires both types of models. This means combining the high resolution models and the general models and concepts into model hierarchies. This is important for several reasons. The first reason is the issue of being able to compare different role-playing simulations. The second one is the issue of conducting series of role-playing simulations, and cumulating knowledge and experience from these simulations in a systematic way. The third reason concerns the use of the role-playing methodology for quasi-experiments.

The experience from this research suggests that it is a rather complex task to formulate such descriptions. What a model hierarchy may contain and how this hierarchy could be formulated for C^2 work at the tactical level in the initial stages of response operations, has been described in chapter 2 (Theoretical background). This description also represents a theoretical base for the conducted simulations.

The theoretical description in chapter 2 builds upon the cybernetic paradigm, which combines cybernetics with decision-making models, and which is the most traditional and the most dominant perspective on C^2 (Builder et al., 1999; Brehmer, 2008; Stanton et al., 2008). Several studies in the domain of the military C^2 such as in the work by Builder et al. (1999), Persson et al. (2000), Pigeau & McCann (2000), Moffat (2003), Brehmer (2005) and Czerwinski (2008), discuss some of the limitations of the cybernetic paradigm when applied to C^2, which should be taken into account when building upon this paradigm. Disaster Research (e.g., Dynes et al., 1981; Dynes, 1994; Granot, 1997; Drabek & McEntire, 2003, Mendonça et al., 2007) argue as well that the traditional C^2 may not always be appropriate and sufficient for all types of response operations.

This has subsequent implications for the presented theoretical description. The model hierarchy should only be used for (a) modeling C^2 in response operations at the tactical level, (b) initial stages of the response operations, and (c) situations where the controller and C^2 system remains in control of the resources and activities taking place in the area of operations to a large extent. For instance, if longer periods of activities, later stages of operations, or responses to catastrophic events should be modeled, alternative models and concepts should be considered, and theoretical descriptions developed.

4.2.2 Evaluation

The issue of concern in this type of simulations is to determine whether the C^2 work conducted by the simulation participants is similar or corresponds well to the C^2 work in naturalistic settings. This is traditionally done by assessing how realistically the participants perceive the simulation and its content as well as how realistic behavior they show during the simulation execution. The evaluation techniques, which have primarily been used, are the evaluation by expert and the self-reflection by participants. The conducted simulations have raised two issues related to the need of additional evaluation techniques.

The first issue concerns evaluation of single simulations. The experience from the conducted simulations suggests that the self-evaluation by participants could sometimes be the only way to gain an understanding of what is going on during the simulations. The self-evaluation in the form of an after-action review combined with expert observations proved to be a suitable technique to assess communication and data sharing in distributed C^2 structures. It this sense, the self-evaluation technique is an invaluable tool. But, additional techniques might be necessary in order to evaluate aspects related to adaptive and improvised C^2 work. Simulation III revealed that in this type of situations the participants may not have the necessary frame of reference to use in order to compare the experiences from the simulation with their real-life experiences. This restrains the use of the self-evaluation technique. In this research, only experienced decision-makers, commanders and operators took a part in the conducted simulations. But the same issue becomes important when novices should participate in this type of simulations as they do not have the necessary frame of reference either.

The second issue is related to evaluation of multiple simulations, generally of different type, in order to compare them. The evaluation by experts and the self-reflection by participants are intended for evaluation of single simulations with respect to their content. They are not adequate for evaluation of simulations for other purposes. Other types of evaluation techniques are thus necessary. Which additional techniques are suitable is a question closely related to the issue of coherent theoretical descriptions.

4.2.3 Methods for analysis of context-bound data

An issue related to the role-playing simulation approach, but also to analysis of real-life response operations, are methods for analysis of high resolution context-bound data, describing dynamic and non-routine situations. An essential feature of the role-playing simulation approach is the possibility to utilize various data collection techniques and tools in order to gather a wide range of high resolution data. Examples of such data are video footage of face-to-face discussions, traces of exchanged digital data, and recordings of telephone conversations. Moreover, the methodology can be combined with the reconstruction and exploration approach as made in Simulation III. This feature is important due to two main facts. First, the methodology simulates dynamic and non-routine situations in a realistic way and thus it may incorporate a large number of variables for which data need to be collected. Second, the way decision-makers, commanders or operators communicate and share data in present-day response operations is qualitatively and quantitatively different in comparison to operations from just a few years ago. Today, they use various technological artifacts and systems for their communication, and the interactions are thus of multimodal character. This means that a wide range of data on different communication modalities and types of interactions are necessary in order to document the participants' work procedures, use of artifacts and ways of communication.

This requires specific methods, which allow bottom-up data driven analysis, to examine this type of data as experienced in this research. An example of such analysis is the mapping of spatio-temporal distribution of communication and connectivity of communicative acts (e.g., Houghton et al., 2006; Landgren and Nuldén, 2007; Uhr, 2007). In this research, episodic analysis, which originates in linguistics, was employed. This method structures communication by breaking it down into episodes, which involve unbroken chains of collaborative and collective actions bound together by a topical trajectory and/or a common activity. However, additional methods are necessary especially when concerning analysis of adaptive behavior and improvisation.

4.3 Concluding remarks

This thesis concerns C^2 work in emergency and crisis response operations. It addresses two main research questions. The first question is whether it is feasible to simulate and study C^2 work at the tactical C^2 level under the described conditions and circumstances by means of role-playing simulations. If so, the second question is how to conduct role-playing simulations in order to explore this type of C^2 work in a methodologically sound way.

The presented research is based on simulations as methodological means for qualitative research. The utilized simulation approach is scenario-based real-time role-playing simulations grounded in models of C^2 work and response operations. Three simulations have been conducted based on this methodology and are reported in this thesis.

The results from the simulations and from the general work conducted and presented in this thesis suggest that role-playing simulations are a feasible methodology to study C^2 work at the tactical level in the initial stages of response operations. The methodology, as any other methodology has its *pros* and *cons*, and is thus more suitable for certain types of problems and questions and less for others. This thesis documents and summarizes experiences from designing and conducting role-playing simulations of C^2 work. It describes features and characteristics of this type of simulation methodology for C^2 research, design and development. It identifies application and problem areas for which the methodology is suitable. The thesis also provides examples of data, analysis and findings concerning new insights in C^2 work with respect to adaptive behavior and improvisation. Lastly, the thesis identifies three areas for further research: models and model hierarchies, simulation evaluation, and methods for analysis of context-bound data. These areas need to be considered in order to further develop the role-playing simulation approach and its applicability in the emergency and crisis management domain.

REFERENCES

Achterbergh, J., & Vriens, D. (2007). It's all in the game: How to use simulation-games for competitive intelligence and how to support them by ICT. In V. Sugumaran (Ed.), *Intelligent information technologies: Concepts, methodologies, tools and applications* (pp. 1880-1894). Idea Group Inc.

Adamski, A., & Westrum, R. (2003). Requisite imagination: The fine art of anticipating what might go wrong. In E. Hollnagel (Ed.), *Handbook of cognitive task design* (pp. 139-200). Lawrence Erlbaum Associates.

Adelman, L. (1991). Experiments, quasi-experiments, and case studies: A review of empirical methods for evaluating decision support systems. *IEEE Transactions on Systems, Man, and Cybernetics, 21*(2), 293-301.

Akmajian, A., Demers, R.A., Farmer, A.K., & Harnish, R.M. (2001). *Linguistics: An Introduction to Language and Communication*. MIT Press.

Alberts, D.S., Garstka, J.J., Hayes, R.E., & Signori, D.A. (2001). *Understanding information age warfare*. Washington, DC: US Department of Defense.

Alberts, D.S., & Hayes, R.E. (2006). *Understanding command and control*. Washington, DC: US Department of Defense.

Alessi, M. (2000). Simulation design for training and assessment. In H.F. O'Neil & D.H. Andrews (Eds.), *Aircrew training and assessment: methods, technologies, and assessment* (pp. 197-222). Lawrence Erlbaum Associates.

Allard, K. (2002). *Somalia operations: Lessons learned*. Washington, DC: US Department of Defense.

Alexander, D. (2000). Scenario methodology for teaching principles of emergency management. *Disaster Prevention and Management*, *9*(2), 89-97.

Aminoff, H., Johansson, B., & Trnka, J. (2007). Understanding coordination in emergency response. In *Proc. of the 26th EAM European Annual Conference on Human Decision-Making and Manual Control*. Lyngby, DK.

Andersson, B., Arkel, M., Norlin, D., & Näslund-Landernmark, B. (2004). *Översvämningen i Tjeckien sommaren 2002*. Karlstad, SE: Swedish Rescue Services Agency.

Artman, H., & Granlund, R. (1998). Team situation awareness using graphical or textual databases in dynamic decision making. In T. Green, L. Bannon, C. Waren & J. Buckley (Eds.), *Proc. of the 9th ECCE European Conference of Cognitive Ergonomics* (pp. 149-155). Limerick, IR.

Artman, H., & Waern, Y. (1999). Distributed cognition in an emergency co-ordination center. *Cognition, Technology & Work, 1*(4), 237-246.

Artman, H. (1999). Situation awareness and cooperation within and between hierarchical units in dynamic decision making. *Ergonomics*, *42*(11), 1404-1417.

Artman, H. (2000). Team situation assessment and information distribution. *Ergonomics*, *43*(8), 1111-1128.

Artman, H., & Persson, M. (2000). Old practices – new technology: Observations of how established practices meet new technology. In R. Dieng, A. Gibson, L. Kersenty & G. De Michelis (Eds.), *Designing Cooperative Systems* (pp. 35-49). Amsterdam: Ios Press Ohmsha.

Ashby, W.R. (1956). *Introduction to cybernetics*. London: Chapman & Hall.

Ashby, W.R. (1968). Principles of self-organizing system. In W. Buckley (Ed.), *Modern systems research for the behavioral scientist* (pp. 108-122). Chicago: Aldine Publishing Company.

Atkinson, P., Coffey, A., Delamont, S., & Lofland, J. (Eds.). (2001). *Handbook of ethnography*. Sage Publications.

Atkinson, S.R., & Moffat, J. (2007). *The agile organization: From informal networks to complex effects and agility* (2nd ed.). Washington, DC: US Department of Defense.

Babb, E.M., Leslie, M.A., & Van Slyke, M.D. (1966). The potential of business-gaming methods in research. *The Journal of Business, 39*(4), 465-472.

Bakken, B.T., & Gilljam, M. (2002). Dynamic intuition in military command and control: Why it is important, and how it should be developed. *Cognition, Technology & Work*, *5*(3), 197-205.

Beaubien, J.M., Goodwin, G.F., Costar, D.M., Baker, D.P., & Smith, K.A. (2005). Behavioral observation scales. In N. Stanton, A. Hedge, K. Brookhuis, E. Salas & H. Hendrick (Eds.), *Handbook of human factors and ergonomics methods*. CRC Press.

Bernard, H.R. (2000). *Social research methods: Qualitative and quantitative approaches*. Sage Publications.

Beroggi, G.E.G., van Gent, D., Mendonça, D., & Wallace, W.A. (2001). Assessing group decision support systems for emergency response using gaming simulation. In *Proc. of the 8th TIEMS International Emergency Management Society Conference*. Oslo, NO.

Beumier, C. (2007). Industrial area detection during GNEX06. In G. Zeug & M. Pesaresi (Eds.), *Global Monitoring for Security and Stability (GMOSS): Integrated scientific and technological research supporting security aspects of the European Union* (pp. 361-364). JRC Scientific and Technical Reports. Luxembourg: Office for Official Publications of the European Communities.

Bigley, G.A., & Roberts, K.H. (2001). The incident command system: High-reliability organizing for complex and volatile task environments. *Academy of Management Journal*, *44*(6), 1281-1299.

Blandford, A., & Wong, B.L.W. (2004). Situation awareness in emergency medical dispatch. *Int. J. Human-Computer Studies*, *61*(4), 421-452.

Boin, A., Kofman-Bos, C., & Overdijk, W. (2004). Crisis simulations: Exploring tomorrow's vulnerabilities and threats. *Simulation & Gaming*, *35*(3), 378-393.

Boulding, K.E. (1956). General system theory – The skeleton of science. *Management Science*, *2*(3), 197-208.

Boyd, J.R. (1987). *A discourse on winning and loosing* (Document no. M-U 43947). Maxwell Air Force Base, AL: Air University Library.

Bracken, P., & Shubik, M. (2001). War gaming in the information age: Theory and purpose. *Naval War College Review*, *54*(2), 47-60.

Brannick, M.T., & Prince, C. (1997). An overview of team performance measurement. In M.T. Brannick, E. Salas & C. Prince (Eds.), *Team performance assessment and measurement* (pp. 331-355). Lawrence Erlbaum Associates.

Brehmer, B. (1987). System design and the psychology of complex systems. In J. Rasmussen & P. Zunde (Eds.), *Empirical foundations of information and software science III*. New York: Plenun Press.

Brehmer, B. (1991). Modern information technology: Timescales and distributed decision making. In J. Rasmussen, B. Brehmer & J. Leplat (Eds.), *Distributed decision making: Cognitive models for cooperative work* (pp. 193-200). John Wiley & Sons.

Brehmer, B., & Allard, R. (1991). Real-time dynamic decision making: The effects of task complexity and feedback delays. In J. Rasmussen, B. Brehmer & J. Leplat, *Distributed decision making: Cognitive models for cooperative work* (pp. 319-334). John Wiley & Sons.

Brehmer, B. (1992). Dynamic decision making: Human control of complex systems. *Acta Psychologica*, *81*(3), 211-241.

Brehmer, B., & Svenmarck, P. (1995). Distributed decision making in dynamic environments: Time scales and architectures of decision making. In J-P. Caverni, M. Bar-Hillel, F.H. Barron & H. Jungermann (Eds.), *Contributions to decision making – I* (pp. 155-174). Amsterdam: Elsevier Science.

Brehmer, B. (2004). Some reflections on microworld research. In S.G. Schiflett, L.R. Elliot, E. Salas & M.D. Coovert (Eds.), *Scaled worlds: Development, validation and applications* (pp. 22-36). Aldershot: Ashgate.

Brehmer, B. (2005). The dynamic OODA loop: Amalgamating Boyd's OODA loop and the cybernetic approach to command and control. In *Proc. of the 10th ICCRTS Int. Command and Control Research and Technology Symposium*. McLean, VI.

Brehmer, B. (2008). Understanding the function of C2 is the key to progress. *Int. Command and Control Journal*, *1*(1), 211-232.

Brunacini, A.V. (2002). *Fire command: The essential of local IMS* (2nd ed.). Quincy, MA: US National Fire Protection Association.

Brynielsson, J. (2006). *A gaming perspective on command and control* (Doctoral dissertation). Stockholm: Royal Institute of Technology.

Buckley, W. (1968). Society as complex adaptive system. In W. Buckley (Ed.), *Modern systems research for the behavioral scientist* (pp. 490-513). Chicago: Aldine Publishing Company.

Builder, C.H., Bankes, S.C., & Nordin, R. (1999). *Command concepts: A theory derived from the practice of command and control*. Santa Monica, CA: US National Defense Research Institute.

Burgess, R.G. (1984). *In the field: An introduction to field research*. Routledge.

Carroll, J.M., & Rosson, M.B. (1992). Getting around the task-artifact cycle: How to make claims and design by scenario. *ACM Transactions on Information Systems*, *10*(2), 181-212.

Cedergårdh, E., & Wennström, O. (2002). *The elements of command & control: The general principles of command & control in fire and rescue operations*. Karlstad, SE: Swedish Rescue Services Agency.

Cedergårdh, E., & Winnberg, T. (2006). Utformning av ledningsorganisation. In L. Fredholm & A-L. Göransson (Eds.), *Ledning av räddningsinsatser i det komplexa samhället* (pp. 199-251). Karlstad, SE: Swedish Rescue Services Agency.

Checkland, P. (1999). *Systems thinking, systems practice*. John Wiley & Sons.

Checkland, P. (2000). Soft systems methodology: A thirty year retrospective. *Systems Research and Behavioral Science*, *17*(1), 11-58.

Clark, H.H. (1996). *Using language*. Cambridge University Press.

Coakley, T.P. (1992). *Command and control for war and peace*. DIANE Publishing.

Cook, M., Noyes, J.M., & Masakowski, Y. (Eds.). (2007). *Decision making in complex environments*. Aldershot: Ashgate.

Cooper, D.F. (1978). On the design and control of crisis games. *Omega, 6*(5), 460-461.

Cooper, D.F. (1979). The superior commander: A methodology for the control of crisis games. *J. Operational Research Society*, *30*(6), 529-537.

Cooper, D.F., Klein, J.H., McDowell, M.R.C., & Johnson, P.V. (1980). The development of a research game. *J. Operational Research Society*, *31*(2), 191-193.

Crano, W.D., & Brewer, M.B. (2002). *Principles and methods of social research*. Lawrence Erlbaum Associates.

Crichton, M.T., Flin, R., & Rattray, W.A.R. (2000). Training decision makers – Tactical decision games. *J. Contingencies and Crisis Management*, *8*(4), 208-217.

Crichton, M.T. (2001). Decision making in emergencies. *Horizons of Psychology*, *10*(4), 7-22.

Crichton, M., & Flin, R. (2001). Training for emergency management. *J. Hazardous Materials*, *88*(2-3), 255-266.

Crookall, D., Oxford, R., & Saunders, D. (1987). Towards a reconceptualization of simulation: From representation to reality. *Simulation/Games for learning*, *17*(4), 147-171.

Crookall, D., & Saunders, D. (1998). Towards an integration of communication and simulation. In D. Crookall & D. Saunders (Eds.), *Communication and Simulation* (pp. 3-32). Multilingual Matters.

Czerwinski, T.J. (2008). *Coping with the bounds*. Washington, DC: US Department of Defense.

Daft, R.L. (1992). *Organization theory and design* (4th ed.). West Publishing.

Denef, S., Ramirez, L., Dyrks, T., & Stevens, G. (2008). Handy navigation in ever-changing spaces - An ethnographic study of firefighting practices. In G. Marsden, I. Ladeira & P. Kotzé (Eds.), *Proc. of the 7th ACM Conference on Designing Interactive Systems* (pp. 184-192). Cape Town, SA.

Denzin, N.K. (1978). *Sociological methods*. New York: McGraw-Hill.

Downs, C.W., Johnson, K.M., & Fallesen, J.J. (1987). *Analysis of feedback in after action reviews* (ARI technical report 745). Arlington, VA: US Army Research Institute for Behavioral and Social Sciences.

Drabek, T.E., & Haas, J.E. (1967). Realism in laboratory simulation: Myth or method? *Social Forces*, *45*(3), 337-346.

Drabek, T.E., & McEntire, D.A. (2003). Emergent phenomena and the sociology of a disaster. *Disaster Prevention and Management*, *12*(2), 97-112.

Driskell, J.E., Radtke, P.H., & Salas, E. (2003). Virtual teams: Effects of technological mediation on team performance. *Group Dynamics: Theory, Research and Practice*, *7*(4), 297-323.

Dynes, R.R., Quarantelli, E.L., & Kreps, G.A. (1981). *A perspective on disaster planning* (Report Series #11). Disaster Research Center. Newark, DE: University of Delaware.

Dynes, J.E. (1994). Community emergency planning: False assumptions and inappropriate analogies. *Int. J. Mass Emergencies and Disasters*, *12*(2), 141-158.

Feinstein, A.H., & Cannon, H.M. (2002). Constructs of simulation evaluation. *Simulation & Gaming*, *33*(4), 425-440.

Fitts, P.M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *J. Experimental Psychology*, *47*(6), 381-391.

Frey, L.R., Gouran, D.S., & Poole, M.S. (Eds.) (1999). *The handbook of group communication theory and research*. Sage Publications.

Flood, R.L. (2000). A brief review of Peter B. Checkland's contribution to systemic thinking. *Systemic Practice and Action Research*, *13*(6), 723-731.

Fredholm, L. (1991). *Development of rescue tactics: Analysis and proposed methods* (FOA C 50089-5.3). Stockholm: Swedish National Defence Research Establishment.

Fredholm, L. (1997). *Att leda stora räddningsinsatser: Svagheter och utvecklingsmöjligheter*. Karlstad, SE: Swedish Rescue Services Agency.

Friman, H., & Derefeldt, G. (2004). Evaluation of human perspectives in systems of systems: A challenge of the future modelling and simulation development. In *Proc. of the 9th ICCRTS Int. Command and Control Research and Technology Symposium*. Copenhagen, DK.

Fussell, S.R., Kraut, R.E., Lerch, F.J., Scherlis, W.L., McNally, M.M., & Cadiz, J.J. (1998). Coordination, overload and team performance: Effects of team coordination strategies. In *Proc. of the ACM conference on Computer Supported Cooperative Work* (pp. 275-284). Seattle, WA.

Garbis, C. (2002). *The cognitive use of artifacts in cooperative process management: rescue management and underground line control* (Doctoral dissertation). Linköping Studies in Art and Science. Linköping, SE: Linköpings universitet.

Gestrelius, K. (1998). *Simulation and training games: Experiential learning*. Huskvarna: SAAB Training Systems.

Gonzales, C., Vanyukov, P., & Martin, M.K. (2005). The use of microworlds to study dynamic decision making. *Computers in Human Behavior*, *21*(2), 273-286.

Gould, J.E. (2001). *Concise handbook of experimental methods for the behavioral and biological sciences*. CRC Press.

Granlund, R. (1997). *C3Fire – A microworld supporting emergency management training* (Licentiate thesis). Linköping Studies in Science and Technology. Linköping, SE: Linköpings universitet.

Granlund, R., Johansson, B., Persson, M., Artman, H., & Mattsson, P. (2001). Exploration of methodological issues in micro-world research – Experience from research in team decision making. In *Proc. of the 1st Workshop on Cognitive Research with Microworlds* (pp. 73-82). Granada, ES.

Granlund, R. (2002). *Monitoring distributed teamwork training* (Doctoral dissertation). Linköping Studies in Science and Technology. Linköping, SE: Linköpings universitet.

Granlund, R., & Johansson, B. (2003). Monitoring distributed collaboration in C3Fire microworld. In S.G. Schiflett, L.R. Elliott, E. Salas & M.D. Coovert (Eds.), *Scaled worlds: Development, validation and applications*. Aldershot: Ashgate.

Granlund, R. (2004). Monitoring experiences from command and control research with C3Fire microworld. *Cognition, Technology & Work*, *5*(3), 183-190.

Granot, H. (1997). Emergency inter-organizational relationships. *Disaster Prevention and Management*, *6*(5), 305-310.

Grant, T., & Kooter, B. (2005). Comparing OODA & other models as operational view C2 architecture. In *Proc. of the 7th ICCRTS Int. Command and Control Research and Technology Symposium*. McLean, VA.

Green, W.G. III (2000). *Exercise alternatives for training emergency management command center staff*. Universal Publishers.

Gu, Q., & Mendonça, D. (2005). Patterns of group information-seeking in a simulated emergency response environment. In B. Van de Walle & B. Carlé (Eds.), *Proc. of the 2nd ISCRAM Int. Conference on Information Systems for Crisis Response and Management* (pp. 109-116). Brussels, BE.

Hartmann, S. (1996). The world as a process: Simulations in the natural and social sciences. In R. Hegselmann, U. Mueller & K.G. Troitzsch (Eds.), *Modelling and simulation in the social sciences from the philosophy of science point of view, theory and decision library* (pp. 77-100). Dordrecht: Kluwer Academic Publishers.

Haslett, B. (1987). *Communication: Strategic action in context*. Lawrence Erlbaum Associates.

Heath, R.L. & Bryant, J. (2000). *Human communication theory and research: Concepts, contexts, and challenges* (2nd ed.). Lawrence Erlbaum Associates.

Hirokawa, R.Y., & Poole, M.S. (Eds.). (1996). *Communication and group decision-making* (2nd ed.). Sage Publications.

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

Hollnagel, E. (1998a). Context, cognition, and control. In Y. Waern (Ed.), *Co-operation in process management – Cognition and information technology* (pp. 27-52). Taylor & Francis.

Hollnagel, E. (1998b). *Cognitive reliability and error analysis method CREAM*. Elsevier Science.

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

Houghton, R.J., Baber, C., McMaster, R., Stanton, N.A., Salmon, P., Stewart, R., et al. (2006). Command and control in emergency services operations: A social network analysis. *Ergonomics*, *43*(8), 1167-1189.

Howie, D.E., & Vicente, K.J. (1998). Measures of operator performance in complex, dynamic microworlds: advancing the state of the art. *Ergonomics*, *41*(4), 485-500.

Hutchins, E. (1995). *Cognition in the wild*. MIT Press/Cambridge MASS.

Hutchins, E. (2001). Cognitive artifacts. In R.A. Wilson & F.C. Keil (Eds.), *The MIT encyclopedia of the cognitive sciences* (pp. 126-128). MIT Press.

Ingrassia, P.L., Geddo, A., Lombardi, F., Calligaro, S., Prato, F., Tengattini, M., et al. (2005). Objective evaluation in a disaster drill: Accuracy of triage operations. In *Proc. of the 3rd Mediterranean Emergency Medicine Congress.* Nice, FR.

Jentsch, F., & Bowers, C. (2005). Team communication analysis. In N. Stanton, A. Hedge, K. Brookhuis, E. Salas & H. Hendrick (Eds.), *Handbook of human factors and ergonomics methods*. CRC Press.

Jenvald, J. (1999). *Methods and tools in computer-supported taskforce training* (Doctoral dissertation). Linköping Studies in Science and Technology. Linköping, SE: Linköpings universitet.

Jenvald, J., & Morin, M. (2004). Simulation-supported live training for emergency response in hazardous environments. *Simulation & Gaming*, *35*(3), 363-377.

Jobidon, M-E., Breton, R., Rousseau, R., & Tremblay, S. (2006). Team response to workload transition: The role of team structure. In *Proc. 50th Annual Meeting of the Human Factors and Ergonomics Society*. San Francisco, CA.

Johansson, B. (2003). *Feedforward control in dynamic situations* (Licentiate thesis). Linköping Studies in Science and Technology. Linköping, SE: Linköpings universitet.

Johansson, B. (2005). *Joint control in dynamic situations* (Doctoral dissertation). Linköping Studies in Science and Technology. Linköping, SE: Linköpings universitet.

Johansson, B., & Hollnagel, E. (2007). Pre-requisites for large scale coordination. *Cognition, Technology & Work*, *9*(1), 5-13.

Johansson, B., Trnka, J., & Granlund, R. (2007). The effect of geographical information systems on a collaborative command and control task. In B. Van den Walle, P. Burghardt & C. Nieuwenhuis (Eds.), *Proc of the 4th ISCRAM Int. Conference on Information Systems for Crisis Response and Management* (pp. 191-200). Delft, NL.

Johansson, P. (2000). *Effektiv insatsledning – några teoretiska grunder för ledning av polis- och räddningsinsatser*. Karlstad, SE: Swedish Rescue Services Agency.

Johansson, P. (2007). *Förslag till insatsstrategiska dimensioner och insatsstrategisk cykel för ledning av räddningsinsatser*. Karlstad, SE: Swedish Rescue Services Agency.

Jones, P.E., & Roelofsma, P.H.M.P. (2000). The potential for social contextual and group biases in team decision-making: biases, conditions and psychological mechanism. *Ergonomics*, *43*(8), 1129-1152.

Jorgensen, D.L. (1989). *Participant observation: A methodology for human studies*. Sage Publications.

Kaiser, M., Larsson, P., & Hörnsten Friberg, L. (2004). *Krishantering med en vidgad syn på nätverksorganisering* (FOI-R—1248—SE). Stockholm: Swedish Defence Research Agency.

Keithly, D.M., & Ferris, S.P. (1999). Auftragstaktik, or directive control, in joint and combined operations. *Parameters*, *29*(3), 118-133.

Kelly, C.R. (1968). *Manual and automatic control*. New York: Willey.

Killian, L.M. (2002). An introduction to methodological problems of field studies in disasters. In R.A. Stallings (Ed). *Methods of disaster research* (pp. 49-93). Xlibris.

Kleiboer, M. (1997). Simulation methodology for crisis management support. *J. Contingencies and Crisis Management*, *5*(4), 198-206.

Klein, G.A. (1997). An overview of naturalistic decision making applications. In C.E. Zsambok & G.A. Klein (Eds.), *Naturalistic Decision Making* (pp. 49-60). Lawrence Erlbaum Associates.

Klein, G.A. (1999). *Sources of power: How people make decisions*. MIT Press.

Klein, J.H., & Cooper, D.F. (1982). Cognitive maps of decision-makers in a complex game. *J. Operational Research Society*, *33*(1), 63-71.

Klein, J.H. (1985). The abstraction of reality for games and simulations. *Int. J. Operational Research Society*, *36*(8), 671-678.

Klein, J.H. (1988). The level of interpretation of games. *Int. J. Operational Research Society*, *39*(6), 527-535.

Kokinov, B. (1995). A dynamic approach to context modeling. In P. Brezillon & S. Abu-Hakima (Eds.), *Proc. of the IJCAI-95 Workshop on Modeling Context in Knowledge Representation and Reasoning* (pp. 199-209). Paris: Laforia.

Kraus, S., Wilkenfeld, J., Harris, M.A., & Blake, E. (1999). The hostage crisis simulation. *Simulation & Gaming*, *23*(4), 398-416.

Lacroix, V., Lotz-Iwen, H-J., Zeil, P., & Pesaresi, M. (2008). The GMOSS experience. In *Proc. of the 3rd Int. Conference on Information and Communication Technologies: From Theory to Applications*. Los Alamitos, CA: Institute of Electrical and Electronics Engineers.

Lagerlöf, J., & Pallin, K. (1999). Doctrine and command in the Swedish armed forces. In *Proc. of the CCRTS Command and Control Research and Technology Symposium*. Newport, RI.

Landgren, J. (2007). *Designing information technology for emergency response* (Doctoral dissertation). Gothenburg Studies of Informatics. Gothenburg: IT University of Göteborg.

Landgren, J., & Nuldén, U. (2007). A study of emergency response work: Patterns of mobile phone interaction. In *Proc. of the SIGCHI conference on Human factors in computing systems* (pp. 1323-1332). San Jose, CA.

Lardinois, C. (1989). Simulation, gaming and training in a competitive, multimodal, multicompany, intercity passenger-transportation environment. *J. Operational Research Society*, *40*(10), 849-861.

Larsson, G. (2005). *Ledarskapsteoretiska aspekter på ledning av räddningsinsatser*. Karlstad, SE: Swedish Rescue Services Agency.

Larsson, G. (2006). Ledarskapsteoretiska reflektioner. In L. Fredholm & A-L. Göransson (Eds.), *Ledning av räddningsinsatser i det komplexa samhället* (pp. 127-154). Karlstad, SE: Swedish Rescue Services Agency.

Leeds-Hurwitz, W. (1993). *Semiotics and communication: Signs, codes, cultures*. Lawrence Erlbaum Associates.

Lewis-Beck, M.S., Bryman, A., & Liao, T.F. (2003). *The Sage encyclopedia of social science research methods* (Volume II). Sage Publications.

Lindgren, I., & Smith, K. (2006). National patterns of teamwork during an emergency management simulation. In *Proc. 50th Annual Meeting of the Human Factors and Ergonomics Society*. San Francisco, CA.

Lindgren, I. (2007). *Towards the mitigation of cultural barriers to communication and cooperation* (Licentiate thesis). Linköping Studies in Science and Technology. Linköping, SE: Linköpings universitet.

Littlejohn, S.W. (2002). *Theories of human communication* (7th ed.). Wadsworth, CA: Belmont.

Lowry, R.S. (2008). *The Gulf War chronicles: A military history of the first war with Iraq*. iUniverse Star.

Mabry, E.A. (1999). The systems metaphor in group communication. In L.R. Frey, D.A. Gouran & M.S. Poole (Eds.), *The handbook of group communication theory and research* (pp. 71-91). Sage Publications.

Mackenzie, C., Hu, P.F-M., Fausboll, C., Nierlich, M., Benner, T., Gagliano, D., et al. (2007). Challenges to remote emergency decision-making for disasters and Homeland Security. *Cognition, Technology & Work*, *9*(1), 15-24.

Mayk, I., & Rubin, I. (1988). Paradigms for understanding C3, anyone? In S.E. Johnson & A. H. Levis (Eds.), *Science of command and control: Coping with uncertainty* (pp. 48-61). Washington, DC: AFCEA International Press.

Mendonça, D., Beroggi, G.E.G., & Wallace, W.A. (2003). Evaluating support for improvisation in simulated emergency scenarios. In *Proc. of the 36th Hawaii Int. Conference System Sciences*. Big Island, HI.

Mendonça, D., Harrald, J., & Jefferson, T. (2007). Emergent interoperability: Collaborative adhocracies and mix and match technologies in emergency management. *Communications of the ACM*, *50*(3), 45-49.

Mihram, G.A. (1972). Some practical aspects of the verification and validation of simulation models. *Operational Research Quarterly*, *23*(1), 17-29.

Miller, G.A. (1968). What is information measurement? In W. Buckley (Ed.), *Modern systems research for the behavioral scientist* (pp. 123-128). Chicago: Aldine Publishing Company.

Miller, T.E., & Woods, D.D. (1997). Key issues for naturalistic decision making researchers in system design. In C.E. Zsambok & G.A. Klein (Eds.), *Naturalistic decision making* (pp. 141-150). Lawrence Erlbaum Associates.

Moffat, J. (2003). *Complexity theory and network centric warfare*. Washington, DC: US Department of Defense.

Morin, M. (2002). *Multimedia representations of distributed tactical operations* (Doctoral dissertation). Linköping Studies in Science and Technology. Linköping, SE: Linköpings universitet.

Mund, J-P., Kranz, O., Schneiderhan, T., & Voigt, S. (2008). Experiences of capacity building activities with GMES and GEOSS. In *Proc. of the 1st EARSeL Workshop on Education and Training*. Istanbul, Turkey.

NATO (2006). *Exploring new command and control concepts and capabilities*. Research Task Group on System Analysis and Studies No. 050 (RTG SAS-050), NATO Research and Technology Organisation.

Neisser, U. (1976). *Cognition and reality*. San Francisco: W.H. Freeman.

Nickens, T., Liu, D., & Vincenzi, D.A. (2008). Decision making under crisis conditions: A training and simulation perspective. In D.A. Vincenzi & J.A. Wise (Eds.), *Human factors in simulation and training* (pp. 321-331). CRC Press.

Niemeyer, K. (2003). Modelling and simulation in defence, *Information & Security*, *12*(1), 19-42.

Norman, D.A. (1991). Cognitive artifacts. In J.M. Carroll (Ed.), *Designing interaction: Psychology at the human-computer interface* (pp. 17-38). Cambridge University Press.

Nuldén, U. (2003). Investigating police practice for design of IT. In *Proc. of the CHI 2003 Conference on Human Factors in Computing Systems* (pp. 820-821). Miami, FL.

Orasanu, J., & Salas, E. (1993). Team decision making in complex environments. In G.A. Klein, J. Orasanu, R. Calderwood & C.E. Zsambok (Eds.), *Decision making in action: Models and methods* (pp. 327-345). Norwood, NJ: Ablex Publishing.

Parson, E.A. (1996). What can you learn from a game? In R. Zeckhauser, R.L. Keeney & J.K. Sebenius (Eds.), *Wise choices: Decision, games, and negotiations* (pp. 233-252). Harvard Business Press.

Payne, C.F. (1999). Contingency plan exercises. *Disaster Prevention and Management*, *8*(2), 111-117.

Perla, P.P. (1990). *The art of wargaming*. Annapolis: U.S. Naval Institute.

Persson, M., & Worm, A. (2002). Information experimentation in command and control. In *Proc. of the 2002 Command and Control Research and Technology Symposium*. Monterey, CA.

Persson, P-A. (2000). *Bringing power and knowledge together: Information systems design for autonomy and control in command work* (Doctoral dissertation). Linköping Studies in Science and Technology. Linköping, SE: Linköpings universitet.

Persson, P-A., Nyce, J.M., & Eriksson, H. (2000). Command and control: A biased combination? In C. McCann & R. Pigeau (Eds.), *The human in command: Exploring the modern military experience* (pp. 201-216). Springer.

Persson, P-A. (2004). Toward an understanding of the service-based command system. In *Proc. of the 9th ICCRTS Command and Control Research and Technology Symposium*. Monterey, CA.

Perrow, C. (1984). *Normal accidents: Living with high-risk technologies*. New York: Basic Books.

Perry, R.W. (2004). Disaster exercise outcomes for professional emergency personnel and citizen volunteers. *J. Contingencies and Crisis Management*, *12*(2), 64-75.

Peterson, D.M., & Perry, R.W. (1999). The impact of disaster exercise on participants. *Disaster Prevention and Management*, *8*(4), 241-254.

Petrescu-Prahova, M.G., & Butts, C.T. (2005). *Emergent coordination in the World Trade Center disaster* (Paper #36). Institute for Mathematical Behavioral Sciences. Irvine, CA: University of California.

Pierce, C.S. (1958). *Collected papers of Charles Sanders Pierce, Vols. VII-VIII* (A.W. Burks, Ed.). Cambridge University Press.

Pigeau, R., & McCann, C. (2000). Redefining command and control. In C. McCann & R. Pigeau (Eds.), *The human in command: Exploring the modern military experience* (pp. 163-184). Springer.

Resch, B., Schmidt, D., & Blaschke, T. (2007). Enabling geographic situational awareness in emergency management. In *Proc. of the 2nd Geospatial Integration for Public Safety Conference*. New Orleans, LA.

Rankin, W.J., Gentner, F.C., & Crissey, M.J. (1995). After action review and debriefing methods: Technique and technology. In *Proc. of the 17th Interservice/Industry Training Systems and Education Conference* (pp. 252-261). Albuquerque, NM.

Rasmussen, J., Brehmer, B., & Leplat, J. (Eds.). (1990). *Distributed decision making: Cognitive models for cooperative work*. John Wiley & Sons.

Rochlin, G.I., & Demchak, C.C. (1991). The Gulf War: Technological and organizational implications. *Survival*, *33*(3), 260-273.

Rochlin, G.I. (1999). Safe operations as a social construct. *Ergonomics*, *42*(11), 1549-1560.

Rochlin, G.I. (2000). A rational choice of error: Comments on the JCO accident report. *Cognition, Technology & Work*, *2*(4), 232-234.

Rolfe, J. (1991). SAGSET 1990 – The proof of the pudding: The effectiveness of games and simulations, *Simulations/Games for Leaning*, *21*(2), 99-117.

Rubel, R.C. (2001). War-gaming network-centric warfare. *Naval War College Review*, *54*(2), 61-74.

Schmitt, J. (1994). *Mastering tactics: Tactical decision game workbook*. Quantico, VA: Marine Corps Association.

Schmidt, G., & Wilhelm, W.E. (2000). Strategic, tactical and operational decisions in multi-national logistics networks: a review and discussion of modelling issues. *Int. J. Production Research*, *38*(7), 1501-1523.

Scott, T.D. (1983). *Tactical engagement simulation after action review guidebook* (ARI research product 83-13). Arlington, VA: US Army Research Institute for Behavioral and Social Sciences.

Shannon, C., & Weaver, W. (1949). *The mathematical theory of communication*. University of Illinois Press.

Shattuck, L., & Woods, D.D. (2000). Communication of intent in military command and control systems. In C. McCann & R. Pigeau (Eds.), *The human in command: Exploring the modern military experience* (pp. 279-292). New York: Kluwer Academic/Plenum Publishers.

Shen, S.Y., & Shaw, M.J. (2004). Managing coordination in emergency response systems with information technologies. In *Proc. of the 10th Americas Conference on Information Systems* (pp. 2120-2120). New York, NY.

Shubik, M. (1972). On the scope gaming. *Management Science*, *18*(5), 20-36.

Silvert, W. (2001). Modelling as a discipline. *Int. J. General Systems*, *30*(3), 261-282.

Silverman, D. (1997). The logics of qualitative research. In R. Dingwall & G. Miller (Eds.), *Context and method in qualitative research* (pp. 12-25). Sage Publications.

Skyttner, L. (2001). *General systems theory*. World Scientific.

Stallings, R.A. (2002). Methods of disaster research: Unique or not? In R.A. Stallings (Ed). *Methods of disaster research* (pp. 21-44). Xlibris.

Stallings, R.A. (2006). Methodological issues. In H. Rodríguez, E.L. Quarantelli & R.R. Dynes (Eds.), *Handbook of disaster research* (pp. 55-82). Springer.

Stanton, N., Hedge, A., Brookhuis, K., Salas, E., & Hendrick, H. (Eds.). (2005). *Handbook of human factors and ergonomics methods*. CRC Press.

Stanton, N., Baber, C., & Harris, D. (2008). *Modelling command and control*. Aldershot: Ashgate.

Stout, R.J., Cannon-Bowers, J.A., Salas, E., & Milanovich, D.M. (1999). Planning shared mental models, and coordinated performance: An empirical link is established. *Human Factors*, *41*(1), 61-71.

Svenmarck, P., & Brehmer, B. (1991). D3Fire, an experimental paradigm for the study of distributed decision making. In B. Brehmer (Ed.), *Distributed decision making*, Roskilde, DK: Risö National Laboratory.

Svensson, S. (1998). *Solving tactical problems using control engineering: System identification and modelling* (Report 1017). Institute of Fire Safety Engineering. Lund, SE: Lund University.

Svensson, S. (2002). *The operational problem of fire control* (Doctoral dissertation). Institute of Fire Safety Engineering. Lund, SE: Lund University.

Svensson, S., Cedergårdh, E., Mårtensson O., & Winnberg, T. (2005). *Taktik, ledning, ledarskap.* Karlstad, SE: Swedish Rescue Services Agency.

Thomas, L.C. (1984). *Games, theory and applications*. Courier Dover Publications.

Thordsen, M.L., & Klein, G.A. (1989). Cognitive processes of the team mind. In *Proc. of the IEEE Int. Conference on Systems, Man, and Cybernetics* (pp. 46-49). Cambridge, MA.

Thorstensson, M. (2008). *Using observers for model based data collection in distributed tactical operations* (Licentiate thesis). Linköping Studies in Science and Technology. Linköping, SE: Linköpings universitet.

Tiede, D., & Lang, S. (2007). Pseudo-realistic and analytical 3D views – conditioned information for security scenarios. In G. Zeug & M. Pesaresi (Eds.), *Global Monitoring for Security and Stability (GMOSS): Integrated scientific and technological research supporting security aspects of the European Union* (pp. 251-259). JRC Scientific and Technical Reports. Luxembourg: Office for Official Publications of the European Communities

Trnka, J., & Jenvald, J. (2006). Role-playing exercise – A real-time approach to study collaborative command and control. *Int. J. Intelligent Control and Systems*, *11*(4), 218-228.

Trnka, J., Johansson, B., & Granlund, R. (2006). Information support in collaborative command and control work – An empirical research using a role-playing exercise approach. In *Proc. of the 11th ICCRTS Int. Command and Control Research and Technology Symposium*. Cambridge, UK.

Trnka, J., & Johansson, B. (2009). Collaborative command and control practice: Adaptation, self-regulation and supporting behavior. *Int. J. Information Systems for Crisis Response and Management*, *1*(2), 47-67.

Trnka, J., Kemper, T., & Schneiderbauer, S. (2009). Do expert teams in rapid crisis response use their tools efficiently? In B. Van de Walle, M. Turoff & R. Hiltz (Eds.), *Advances in Management Information Systems: Volume* *on Information Systems for Emergency Management* (pp. 126-159). Armonk, NY: M.E. Sharpe.

Trnka, J., Lundberg, J., & Jungert, E. (submitted). A model-based simulation approach to study role improvisation of a command staff. *IEEE Transactions on System, Man, and Cybernetics, Part A: Systems and Humans*.

Törnqvist E., K. (2004). *Bland grynnor och blindskär. Kommunikation, lärande och teknik i samarbetsprojektet Sjöräddning* (Doctoral dissertation). Linköping Studies in Arts and Science. Linköping, SE: Linköpings universitet.

Uhr, C. (2007). *Behind the Charts – Exploring Conditions for High Level Emergency Response Management in a Complex Environment* (Report 1037). Institute of Fire Safety Engineering. Lund, SE: Lund University.

UK CCS (2007). *Dealing with disaster* (3rd ed.). London: UK Civil Contingencies Secretariat (UK CCS).

Urban, J.M., Bowers, C.A., Monday, S.D., & Morgan, B.B. Jr. (1995). Workload, team structure, and communication in team performance. *Military Psychology*, *7*(2), 123-139.

US DoA (2008). *Field manual no. 3-0: Operations*. Washington, DC: US Department of the Army (US DoA).

US FEMA (2007). *Homeland Security exercise and evaluation program – Volume II: Exercise planning and conduct*. Washington, DC: US Federal Emergency Management Agency (US FEMA).

US GAO (2007). *Military training*. Washington, DC: US Government Accountability Office (US GAO).

Vat, K.H. (2005). Modeling human activity systems for collaborative project work: An IS development perspective. *Issues in Informing Science and Information Technology*, *2*, 49-65.

Voigt, S., Trnka, J., Kemper, T., Riedlinger, T., & Husson, A. (2009). Satellite based information to support European crisis response. In B. Jasani, M. Pesaresi, S. Schneiderbauer & G. Zeug (Eds.), *Remote sensing from space - Supporting international peace and security*. Berlin: Springer.

Von Bertalanffy, L. (1968). *General systems theory: Foundations, development, applications*. New York: George Brazille.

Von Bertalanffy, L. (1972). The history and status of general system theory. *The Academy of Management Review*, *12*(4), 407-426.

Von Foerster, H. (1968). From stimulus to symbol: The economy of biological computation. In W. Buckley (Ed.), *Modern systems research for the behavioral scientist* (pp. 170-181). Chicago: Aldine Publishing Company.

Walsh, D.W., Christen, H.T. Jr., Miller, G.T., Callsen, C.E Jr., Cilluffo, F.J., & Maniscalo, P.M. (2005). *National incident management system: Principles and practice*. Jones & Bartlett Publishers.

Weirich, P. (2008). The explanatory power of models and simulations. In P. Weirich, T. Gruene-Yanoff, S. Ruphy & J. Simpson (Eds.), *Philosophical and epistemological issues in simulation and gaming*. Sage Publications.

Wentz, L. (2002). *Lessons from Kosovo: The KFOR experience*. Washington, DC: US Department of Defense.

Wheelan, S.A. (2005). *The handbook of group research and practice*. Sage Publications.

Widder, W. (2002). Auftragstaktik and innere führung: Trademarks of German leadership. *Military Review*, *82*(5), 3-9.

Wiener, N. (1948). *Cybernetics or control and communication in the animal and the machine*. Cambridge: MIT Press.

Winsberg, E. (1999). Sanctioning models: The epistemology of simulation. *Science in Context*, 12 (2), 275-292.

Winsberg, E. (2001). Simulations, models, and theories: Complex physical systems and their representations. *Philosophy of Science*, *68*, 442-454.

Wohl, F.G. (1981). Force management decision requirements for air force tactical command & control. *IEE Transactions in Systems, Man and Cybernetics*, *11*(9), 618-639.

Wolcott, H.F. (1999). *Ethnography: A way of seeing*. Rowman Atlamira.

Woltjer, R. (2005). *On how constraints shape action* (Licentiate thesis). Linköping Studies in Science and Technology. Linköping, SE: Linköpings universitet.

Woltjer, R., Lindgren, I., & Smith, K. (2006a). A case study of information and information technology in emergency management training. *Int. J. Emergency Management*, *3*(4), 332-347.

Woltjer, R., Trnka, J., Lundberg, J., & Johansson, B. (2006b). Role-playing exercises to strengthen the resilience of command and control systems. In G. Grote, H. Günter & A. Totter (Eds.), *Proc. of the 13th ECE European Conference on Cognitive Ergonomics* (pp. 71-78). Zurich, SUI.

Woltjer, R., Smith, K., & Hollnagel, E. (2008). Representation of spatio-temporal resource constraints in network-based command and control. In J.M. Schraagen, L.G. Militello, T. Ormerod & R. Lipshitz (Eds.), *Naturalistic decision making and macrocognition* (pp. 351-372). Aldershot: Ashgate.

Woltjer, R. (2009). *Functional modeling of constraint management in aviation safety and command and control* (Doctoral dissertation). Linköping

Studies in Science and Technology. Linköping, SE: Linköpings universitet.

Woods, D.D., Johannesen, L.J., Cook, R.I., & Sarter, N.B. (1994). *Behind human error: Cognitive systems, computers, and hindsight*. CSERIAC.

Woods, D.D., & Hollnagel, E. (2006). *Joint cognitive systems: Patterns in cognitive systems engineering*. CRC Press.

Wybo, J-L., & Lonka, H. (2002). Emergency management and information society: How to improve synergy? *Int. J. Emergency Management*, *1*(2), 183-190.

Yardley-Matwiejczuk, K.M. (1997). *Role play: Theory and practice*. Sage Publications.

Zacarias, M., Pinto, H.S., & Tribolet, J. (2007). Integrating engineering, cognitive and social approaches for a comprehensive modeling of organizational agents and their context. In B. Kokinov, D.C. Richardson & T.R. Roth-Berghofer (Eds.), *Proc. of the 6th Int. and Interdisciplinary Conference on Modeling and Using Context* (pp. 517-530). Berlin: Springer.

Zetterling, N. (1999). *Konsekvenser av framtida operativa koncept*. Stockholm: Swedish National Defence College.

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