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Future Technology Support of Command and Control

Assessing the impact of assumed future technologies on cooperative command and control

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Abstract

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In response to technological advances, especially in the field of information and communication technology (ICT), the so called revolution in military affairs (RMA) and later the concept of network-centric warfare (NCW) emerged as a theory to further utilize technology for military command and control (C^2). Advocates of the Swedish ROLF 2010-vision and the concept of NCW have made claims and assumptions that future technology will improve mission effectiveness by, for example, increasing the understanding of a current situation and its development, the speed of command, and providing means to utilize more efficient forms of organizations. The scope of this thesis is to critically dissect and assess some of these claims and assumptions.

Four papers are included: (1) An observational study involving military officers participating in a training session at the Swedish National Defence College's command and control laboratory. (2) A study performed with a microworld is presented with a discussion considering using microworlds as a tool for investigating the effects of introducing characteristics of novel technology. (3) An experimental study introducing a method to measure individual's apprehension and assessed development of a situation. (4) Finally, an experiment is presented addressing assumptions of the efficiency of different C^2 architectures and effects of graphical support for communication of intentions.

The overall conclusion is that the strong benefits from implementing new technologies can be questioned. Results from the qualitative observations indicate that traditional working practices are used regardless introduction of technology with future characteristics. The results show that the strong positive effect that networked and technology enhanced C^2 architecture was expected to have generally could not be demonstrated experimentally. However, it appeared that such a C^2 architecture can provide some advantages of C^2 performance over traditional counterparts under conditions of moderate complexity. Under situations of high complexity, neither the networked nor the traditional C^2 architecture performed better than the control condition who lacked C^2 capabilities.

Keywords: command, control, cooperative, collaboration, decision-making, effectiveness, human-computer interaction, microworld, network-centric, military, team

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To Susanne who always supported me in my work
and to my children Elisabeth, Marcus and Johanna.
A long and bumpy journey has finally reached its end…

Outline of the thesis

This thesis consists of two parts. First, the summary part, which outlines the background, positions and drawn conclusions based on the research (chapter 1-7). The second part, the article part, describes and presents results from the research (article I-IV):

Chapter 1 presents an outline of the research, the overall research approach, the scope, and its limitations.
Chapter 2 describes the theoretical framework, methodology, and methods used in this dissertation.
Chapter 3 describes the research context and the work of other researchers related to the field of command and control.
Chapter 4 discusses data and information as enablers for command and control.
Chapter 5 give a summary of the papers and provide their results.
Chapter 6 discusses and present conclusions based on the result.
Chapter 7 provides a summary of this dissertation in Swedish.

List of papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

I Artman, H., Persson, M. (2000) Old Practices - New Technology: Observation of how established practices meet new technology. In R. Dieng, A. Giboin, L. Karsenty & G. De Michelis (Eds.), *Designing Cooperative Systems: The Use of Theories and Models - Proc. of the 5th Int. Conf. on the Design of Cooperative Systems (COOP'2000), 58*, pp. 35-49. Amsterdam: IOS Press.

II Johansson, B., Persson, M., Granlund, R., Mattsson, P. (2003) C3Fire in command and control research. *Cognition, Technology & Work, 5*(3), pp. 191-196. doi 10.1007/s10111-003-0127-x

III Persson, M., Rigas, G. (2007) A measure of situation apprehension, outcome prediction and performance in one microworld. In *Proc. of the 10th IFAC/IFIP/IFORS/IEA Symposium on analysis, design, and evaluation of human-machine systems (IFAC-HMS 2007)*. Korea: Elsevier.

IV Persson, M., Rigas, G. (2014) Complexity: the dark side of network-centric warfare. *Cognition, Technology & Work, 16*(1), pp. 103-115. doi 10.1007/s10111-012-0248-1.

The following is a more detailed description of the papers. In addition, the account to my contribution to the work is provided.

Paper I	**Old Practices - New Technology: Observation of how established practices meet new technology.**
Authors	Henrik Artman and Mats Persson
Publication	In *Proceedings of the 5th International Conference on the Design of Cooperative Systems (COOP'2000), 58*, pp. 35-49.
Abstract	Most technology for command and control units is developed from top-down visions and models of an ideal team and technology fit. Such models seldom pay attention to social and historical practises. In Sweden there is a futuristic command and control post under development. The system is intended for civilian and military handling of crises. In spring 1999, a training session was carried out in an elaborated virtual environment. The session was video recorded. In this paper we present and discuss our observations from this session. We have especially focused on the team organisation and use of technology from a bottom-up perspective. As we suspected we found a clash between old practices and what new technology affords. We describe our observations and discuss them in connection to how the system is coupled to external units. One main conclusion is that the team members seem to be more coupled to their subordinate units than to the command and control team.
My contribution	In this paper, I was the secondary author. I provided expertise both when observing the event and under the audio and video analysis. Furthermore, I was responsible for and performed the data collection. The writing of the article was a joint and iterative process where I had the main responsibility to provide the background of the research, to illuminate assumptions made in the main research projects, and to create the illustrations. My co-author had the main responsibility to compile the findings from our observations.

Paper II	**C3Fire in command and control research.**
Authors	Björn Johansson, Mats Persson, Rego Granlund, and Peter Mattsson
Publication	In *Cognition, Technology & Work, 5*(3), 2003, pp. 191-196.
Abstract	New and envisioned technological means and abilities for exerting command and control have increased the interest of man-machine research in a military context. Although there are many current proposals for how new command and control systems should be designed, many of the proposed properties that are considered advantageous have never been tested or could even be impossible to test in real-world situations. In spite of that, proposed design solutions are generally held valid in many Western countries where developments of major command and control system projects are in progress. An important question is how microworlds can be used for research on team decision-making. The use of microworlds gives us the possibility to create controlled settings and the opportunity to use advanced monitoring tools to study the subjects. Our studies indicate that the microworld concept, even though the simulation is fairly simple, reflects some of the crucial aspects of team-work in dynamic settings. The article presents results from a study in command and control using the C3Fire microworld (http://www.c3fire.org). Results and methodological issues are discussed.
My contribution	In this paper, I was the secondary author where Björn Johansson and I was equally responsible for the writings. The article is based on an original idea of mine to compare C^2 performance between a traditional and a networked condition. I also had the main responsibility for the configuration of the C^3Fire micro-world that was used in the ROLF 2010 environment referred to in the article.

Paper III	**A measure of situation apprehension, outcome prediction and performance in one microworld.**
Authors	Mats Persson and Georgios Rigas
Publication	In *Proceedings of the 10th IFAC/IFIP/IFORS/IEA Symposium on analysis, design, and evaluation of human-machine systems (IFAC-HMS 2007)*. Korea: Elsevier.
Abstract	In this article a measurement method of *situation apprehension* and *outcome prediction* is examined psychometrically. This method has its inspiration in Spearman's theory of intelligence and constitutes an alternative to the concepts of situation awareness and sense making. The measurement approach of certain aspects of understanding that is examined here is specific to the decision making environment (microworld) used, but its general properties, however, should be rather widely applicable. Using one microworld – C3Fire – and an assessment technique of situation apprehension and prediction ability, we studied the relationships between apprehension, prediction, and performance in the microworld. These results indicate that the measurement method used may be psychometrically sound and thus a viable alternative to current approaches to understanding, such as situation awareness and sense making.
My contribution	In this paper, I was the primary author. I designed and performed the experiment, as well as created the procedure for data collection and measuring. Furthermore, I analyzed the data and extracted the results. My co-author supported my work by providing suggestions to ameliorate the text and how to process the data statistically.

Paper IV	**Complexity: the dark side of network-centric warfare.**
Authors	Mats Persson and Georgios Rigas
Publication	In *Cognition, Technology & Work, 16*(1), 2014, pp. 103-115.
Abstract	Military theoretical considerations suggest that a networked command and control architecture will provide a more effective form of command and control under complex operations that demand a high tempo of action. This article presents an experimental study with the purpose to examine team performance under different conditions of command and control architectures and their resilience to complexity. The experiment was performed with the task to extinguish simulated fires in a microworld. Three factors were varied in the experiment: command and control architecture, the number of simulated units, and tempo. The dependent variable was the number of lost cells in the microworld. Three command and control architectures were investigated; *command by negation*, *directive command*, and a *control condition*. The general conclusion from this experiment was that all command and control architectures performed equally poorly under the condition of many subordinate units and fast tempo. This was in contradiction to suggestions made in the military theoretical literature. Command by negation was presumably the more effective command and control architecture under the other conditions.
My contribution	In this paper, I was the primary author. The planning and preparation of the experiment was a joint effort; however, my co-author had the main responsibility for the design. The data collection was a joint effort. I administrated the participants, performed the analysis of data and wrote the article in full.

Selected publications not included in this thesis

i Trnka, J., Persson, M., Hörling, P., Nilsson, S. & Artman, H. (2011). *Framtida ledningscentraler: Slutrapport* (Användarrapport nr. FOI-R-3256-SE). Totalförsvarets forskningsinstitut (FOI), Avd. för informationssystem.

ii Trnka, J., Persson, M., Hörling, P., Nählinder, S. & Artman, H. (2011). *Framtida ledningscentraler: Delrapport 1, omvärldsanalys* (Användarrapport nr. FOI-R-3184-SE). Totalförsvarets forskningsinstitut (FOI), Avd. för informationssystem.

iii Lawson, H. & Persson, M. (2010). Contributions Towards Unifying System Semantics. In *Proc. of the 20 th Annual INCOSE International Symposium*, July 12–15. Chicago: Curran Associates, Inc.

iv Lawson, H. & Persson, M. (2010). Portraying aspects of system life cycle models. In *7 th European Systems Engineering Conference, EuSEC 2010 – Systems Engineering & Innovation*, May 23–26. Stockholm: INCOSE.

v Persson, P-A., Nyce, J. M., Persson, M., Räsänen, M. & Svensson, J-I. (2010). *Från koncept till öppet system – utveckling av operativ och taktisk underrättelsetjänst i den militära insatsorganisationen, för att verka, synas och respekteras* (Nr. Ö 166/2008:49). Försvarshögskolan.

vi Persson, M. (Ed.). (2009). *Aspekter på ledning*. Stockholm: Försvarsmakten.

vii Rigas, G., Persson, M. & Brehmer, B. (2007). Time pressure, complexity and selfsynchronization. In *Proc. of the 10th IFAC/IFIP/IFORS/IEA symposium on analysis, design, and evaluation of human-machine systems (IFAC-HMS 2007)*. Korea: Elsevier.

viii Persson, M. (2004). Ledning: ett perspektiv på nätverk och andra begrepp. I G. Artéus & B. Brehmer (Eds.), *Det nya kriget* (p. 111-149). Stockholm: Försvarshögskolan, Elanders Gotab.

ix Leifler, O., Johansson, B., Persson, M. & Rigas, G. (2004). Development of critiquing systems in networked organizations. In C. Johnson & P. Palanque (Eds.), Human error, safety and systems development, *IFIP 18th world computer congress, TC13/WG13. 57th working conference on human error, safety and systems development, 22-27 august 2004*. Toulouse: France: Kluwer.

x Persson, M. & Worm, A. (2002). Information experimentation in command and control. In *2002 Command and control research and technology symposium*. Monterey, CA.

xi Persson, M. (2001). Future command and control systems: Operational, organisational, and functional prerequisites. In S. C. Holmberg & V. Asproth (Eds.), *Systemics and informatics research seminar on AIH: Applied informatics for improvement of human life, SIMS'01*. Östersund, Sweden.

xii Persson, M. & Johansson, B. (2001). Creativity or diversity in command and control environments. In M. J. Smith, G. Salvendy, D. Harris & R. Koubek (Eds.), In *Proc. of the 9^{th} international conference on human-computer interaction, HCI International 2001* (Vol. 1, pp. 1508-1512). New Orleans: Lawrence Erlbaum and Associates.

xiii Persson, M. (2000). 2024 - Was Orwell right, but 40 years too early? In C. Sundin & H. Friman (Eds.), *ROLF 2010 the way ahead the first step: A collection of research papers* (s. 27-35). Stockholm: Elanders Gotab.

xiv Persson, M. (2000). Visualization of information spaces for command and control: Does technology or efficiency drive present solutions? In C. Sundin & H. Friman (Eds.), *ROLF 2010 the way ahead the first step: A collection of research papers* (s. 144-156). Stockholm: Elanders Gotab.

Contents

Abbreviations

AFCEA Armed Forces Communication and Electronics Association
C^2 command and control
C^3Fire Command, Control and Communication simulation environment[1]
COCOM Contextual Control Model
COP common operational picture
CSCW computer supported cooperative work
CSE cognitive systems engineering
DCog distributed cognition
DDM distributed decision making
DOODA Dynamic Observe, Orient, Decide, Act
DoD United States Department of Defense
DSA distributed situation awareness
DSS decision support systems
ECOM Extended Control Model
FICS Functions, Interactions, Content and Services
FOA Swedish National Defence Research Establishment
FOI Swedish Defence Research Agency[2]
GIS geographical information system
GST general system theory
HCI human computer interaction
HF human factors
HKV Högkvarteret[3]
IRA information requirement analysis
ICT information and communication technology
JCS joint cognitive system
NbF nettverksbasert forsvar[4]
NBF nätverksbaserat försvar[5]
NBD network based defence
NCW network-centric warfare
NEC network enabled capability

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[1] C^3Fire is a research tool that can be used for investigation, training and experimentation of team decision-making and team situation awareness.
[2] 1st of January 2001, FOA and the Aeronautical Research Institute was reorganized and merged into what today is FOI
[3] HKV is a Swedish acronym that stands for the Swedish Armed Forces Headquarters
[4] NbF is a Norwegian acronym that stands for Network Based Defence
[5] NBF is a Swedish acronym that stands for Network Based Defence

OODA Observe, Orient, Decide, Act
PACT People, Activities, Contexts, Technologies
PCW platform centric warfare
RMA revolution in military affairs
ROLF 2010 Rörlig Operativ Ledningsfunktion 2010[6]
RTMTR Response Time Measurement and Training[7]
SA situation awareness
SDT signal detection theory
SNA social network analysis
SNDC Swedish National Defence College
STS sociotechnical systems
SweAF Swedish Armed Forces

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[6]ROLF 2010 is an acronym for a Swedish research project that stands for the Mobile Joint Command and Control System 2010.
[7]RTMTR is a computer software used to train participants in the basic skills needed for managing the C^3Fire microworld.

1. Introduction

R&D is almost always about the future. [...] To the extent that R&D is focused in solving today's problems, they are performing an engineering function rather than R&D.

Rouse and Boff

1.1 Introduction to the problem

As the title reveals, this thesis concern individuals exercising command and control (C^2) in cooperation to achieve some overall and common goal. From a scientific perspective, the title can serve to frame the understanding of the phenomenon of C^2 for development of methods and tools that potentially can increase C^2 efficiency under different conditions.

This thesis address how new information technology supports trained individuals that form a decision-making team, or a "staff of operations," assigned to manage a complex crisis situation that distinguishes itself by raised levels of uncertainty, hostility, and its extension over time. The C^2 work performed by the team members is assumed being supported by future information and communication technology (ICT). A significant part of their work is characterized by interacting with computers for processing and mediating data and information between subordinate levels of command and among the team members themselves. Moreover, the C^2 work environment is featured with several shared information presentation areas. Besides that it is possible to utilize these for displaying real or near-real time information from different sources, they allow a joint construction of representations for the rendering of the situation.

The characteristics of managing a complex, uncertain, and hostile situation outlined above are frequently the case when exercising C^2 in a military context. Comparing exertion of military C^2 with other crisis organizations as the rescue services or police authorities imply some major differences. The most obvious is the military crisis situation's nature where the own freedom to act is likely to be limited because of an adversary's influence over its development. An additional distinction is that military crisis situations usually continue for a long time.

Viewing execution of C^2 as a joint activity implies that participants in a decision-making team have to develop some degree of common understanding to be able to strive for accomplishment of a mission. However, to circumspect to what degree a general goal is fulfilled, it is desirable that means are provided to make such evaluations. In addition, support should be provided to take proper actions based on the evaluations.

Current thinking in the Western world about execution of military C^2 has been shaped in the light of forecasts of future technology innovations and assumptions of what they can provide. In this context, assumed development, and utilization of future ICT often protrudes. For example, while having appropriate means to process and interact with data and information, assumptions are made that a decision-making team will understand a situation better and thus making better and faster decisions how to act upon it.

Within different research communities, ideas and theories of future ICT have been developed in parallel and are intertwined with equivalents in military research. These research efforts extend between on the one hand technicalities of information and communication systems, and on the other hand societal changes viewed as a whole. From this, visions have emerged that describe how both physical and other parts of a military C^2 environment could or should be designed for the future. In all essentials, the visions of how ICT can support execution of C^2 in the future have become widely accepted. Such visions also often express that ICT will simplify the work for commanders to monitor environmental changes and making decisions of how to act appropriately upon those changes.

Military C^2 is normally exercised in a work environment that can be viewed as a complex sociotechnical system, which refers to interrelated social and technical subsystems forming a whole. The line of thought behind sociotechnical systems address problems considering the joint optimization of people and ICT systems. In addition, performance of the sociotechnical system viewed as a whole is inextricably linked to the experiences of those that work within it (Walker, Stanton, & Salmon, 2009).

Based on both recent and historical experiences; however, it seems evident that expected results from technological innovations and their implementation is not always accomplished within the field of military C^2 (e.g., see Higginbottom, 2012; O'Hanlon, 2000; Sterling, 2008; Van Creveld, 1991). Therefore, to accomplish suggested objectives portrayed in visions of future C^2 environments several conditions have to be considered apart from merely implementing new technologies. For example, different aspects and various combinations of human and technological processes, functionality, and design solutions. Thus, there is a need to consider both societal and technological dimensions when novel C^2 systems are engineered. As put forward by Walker et al. (2009, p. 7) it is important to realize that: “people are not rational optimisers and they do not behave like machines.” Therefore, from a design perspective it is not guaranteed that working procedures or processes of C^2 is performed as intended by developers of some new technology. From these arguments, empirical investigations are needed to understand whether properties of new technology will provide support for assumptions made regarding different aspects of C^2 in the future.

1.2 Research agenda and objective

The general framework for this thesis has its origin in a visionary and collaborative research project called *Rörlig Operativ Ledningsfunktion 2010 (ROLF 2010)*[1] at the Swedish National Defence College (SNDC) and the concept of network-centric warfare (NCW). The concept of NCW is further discussed in section 2.1.

The ROLF 2010 project was based on a vision for developing a mobile command post for meeting the demands of a future battlefield (Brehmer, 2007a; Brehmer & Sundin, 2005; Sundin & Friman, 1998, 2000). The vision, however, stretches over matters that concern all levels from technical, individual to societal that may influence the capability to exercise command and control (C^2). For example, how to develop support for; situation awareness (SA) and visualization of a common operational picture (COP); for decision-making under dynamic, hostile, and insecure situations; distribution graphical and traditional representations of made decisions; as well as new forms of organizations, manning principles, and new working methods (Sundin & Friman, 1998). Hence, this thesis represents but a part of the mutual and collaborative research efforts made within the ROLF 2010 project. Beside the foundation of this thesis in the ROLF 2010 project, it also has a close relation to a project called *Aqua*. The Aqua project was intended to develop, implement and/or by other means embody envisioned future technologies expressed in the ROLF 2010-vision. Accordingly, new prototypical technologies were developed in parallel with emulations that provided technological functionality that corresponded to the ROLF 2010-vision and thus implemented in the SNDC C^2 laboratory. By this procedure, means were provided to enable research about technological and other capabilities assumed being present in a future C^2 environment (e.g., see Sundin & Friman, 1998).

This thesis starts from the ROLF 2010-vision and the concept of NCW with an exploratory purpose to evaluate and investigate claims and assumptions about properties of future technologies and their suggested affection on C^2 performance. To illuminate this complex purpose, several studies have been conducted with use of different methods. Accordingly, the main study consists of multiple activities with different objectives. Initially, the objectives were focused on building basic knowledge about general phenomena in an envisioned future C^2 work environment as outlined in the ROLF 2010-vision. Furthermore, if the participants' interaction with available ICT affected their behavior and increased their efficiency as expected. Thereafter the objectives were to apply that knowledge on more precise and controlled studies.

[1] trans. *the Mobile Joint Command and Control System 2010*

The general problems that practitioners of military C^2 currently are exposed to and has to handle is fairly well known. Common between the execution of current and future C^2 is entailing a situation determined by a superior objective or goal. In addition, the resources available to accomplish this goal often are limited. From this follows that available assets have to be utilized efficiently over time. In *Mänsklig styrning av komplexa system*[2] Brehmer (1993) discusses C^2 from a general level. His viewpoint can be considered as systemic where the controlling and the controlled parts can be regarded as a compound system. Brehmer argue that the presumptions for control are the same independent of whether control is manually exercised or if it is automated. Besides that a system must be governed by a goal condition, three additional requirements are to be reached to make it possible to exercise control (p. 18):

- the system's current state must be observable,
- the system's state must be possible to influence, and
- it must exist some kind of model that describe what happens if one thing or another, or nothing, is done to or with the system

By elaborating these issues, Brehmer concludes that one of the most important tasks a decision maker has is to develop a model of the system viewed as a whole. However, besides Brehmer's conclusions when considering the first item of observability above, the system's state must also be intelligible and understandable. In addition, to develop a model that represent the system viewed as a whole should also include how decision-making is performed. Contrary to Brehmer's position, where an individual is in focus for studying decision-making, the initial problem elaborated in this study is directed to a collaborative effort of both the commander and his/her supporting members forming a decision-making team, or a "staff of operations," assigned to handle a complex situation. Complexity can be considered being constituted by many things that interact with one another in counterintuitive ways (Boardman & Sauser, 2008). With this perspective, an emerging or ongoing crisis situation can be viewed as a system in its own right (Lawson, 2010). Degele (2008) note; however, that classical system-theoretic concepts of complexity consider only the characteristics of interdependence and emergence. These concepts then structurally determine complexity by investigating relationships of the elements and should be regarded as static complexity, or *complicatedness*.

This in contrary to *complex systems* that may take on a variety of states within a short time. Accordingly, the classical system-theoretic concepts inability to describe complexity is owed to the insufficient consideration of the temporal dimension. Degele (2008, p. 56) writes: "A multitude of elements, hierarchies, and interdependencies do not yet turn a system complex, but merely complicated. In order for it to be complex, it takes system state

[2] trans. *Human control of complex systems*

modifications, at high speed." Thus, a complex system does not necessarily need to include many elements, but dynamic components of irreversibility and non-linearity that are responsible for the difficulty to decompose and to describe it. Therefore, *time* is a factor that generates complexity and can transform a complicated system into a complex one. For the purpose of this thesis, a working definition of complexity is provided as:

> The sum of the variety created by the number of elements controlled; their status; the relations between these elements and their interactions; and any combination thereof that form a C^2 situation under which decision-makers have limited time making decisions to act.

In addition, a *proxy* of complexity is used in this thesis that refers to—a command function (a single commander or a staff of operations) and the organization under its control; the number of interconnected elements that must be controlled; the degree of uncertainty; and the tempo under which the control function has to manage a dynamically developing situation.

In real situations, handling complexity that emerges from a crisis situation is seldom an activity carried out by a single commander. Although a designated military commander has an individual responsibility for accomplishing a mission, it is generally common that tasks are distributed and shared among cooperating members of a decision-team to create a shared model, or a common operational picture (COP), which is utilized to handle the situation and to exercise C^2. Accordingly, being able to create a proper, shared and an efficient model that can handle the uncertainties and the complexity characterizing a crisis situation, commanders on different levels must seek support among available competencies. It can also be stated that the basic purpose of modeling is to gain insights upon which decision-making can be made. From this follows that model creation is a cooperative activity where the process of modeling can be as important as the result. Thus, the accuracy of "the model" is important to several aspects of decision-making and attributing technologies to improve such work is appealing. So, using new technologies may provide new means of creating models that facilitate the processes of becoming aware of and to understand "what is going on"; new ways of organizing work; new possibilities of organizing available assets; and thus new ways to ensure the assets' effect and endurance.

Accordingly, introduction of new technology is often intertwined with one or several aims to provide conditions for increased efficiency. To bring in new technology can, however, imply that unforeseen and unwanted effects occur (Bainbridge, 1987, cf., section 2.6). Thus, to assume that new technologies spontaneously will change working procedures according to assumed needs or capabilities are not obvious and need to be investigated. Therefore, introduction of new technology needs to be linked to the introduction of new ways to organize work and new working procedures that are controlled top-down. To do that, however, imply that the working procedures have to be known, which requires empirical data. Another alternative is to introduce new technology and promote bottom-up design of working procedures, which might require other types of empirical data. However, both alternatives can initially be preceded by hypotheses of the nature of future C^2 work. Both the ROLF 2010-vision and the concept of NCW express a variety of assumptions and claims where characteristics of future technology is central and viewed as an enabler to achieve more effective and efficient C^2. Some of the ROLF 2010-vision's guidelines for design of a C^2 environment for the future was based on the following assumptions (Sundin & Friman, 1998, 2000):

1. The more accessible information the fewer factors of uncertainty will emerge.
2. Everybody in need of some piece of information will have access to it.
3. Command and control will be simplified as it can be executed distributed.
4. Since command and control are distributed it follows that allocation of resources is easier, which might reduce the risk of excessive resource depletion.
5. New technology will promote creative discussions about operational problems and thus contribute to and facilitate the development of a joint operational idea.

From the definition of NCW (cf., section 2.1), characteristics of future technology are assumed provide the following advantages:

6. Information superiority compared to an adversary.
7. Increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness.
8. Increased speed of command.
9. Higher tempo of operations.
10. Better weapon precision when engaging an adversary.
11. Increased survivability.
12. Capability of self-synchronization for adaption to the situation and to become more efficient.

From the general capabilities that technology will provide in the future, its characteristics can be outlined as follows. All units, sensors, "shooters" and C^2 functions on all levels of command are fully connected to a high capability communication network. The network has properties that admit transmission of vast amounts of data in high speed throughout the organization. Therefore, entities connected to the network are allowed to automatically update discovered changes of the situation in near or real-time. Individual and shared display areas will admit novel ways to present, interact, process, and distribute data and information. In addition, these display areas will increase decision-teams capability of becoming aware of and to faster understand the situation and to make decisions of how to act upon it. Furthermore, new ways to interact with shared displays will provide new means to use audio, video and new graphical means to communicate with interconnected units. In addition, since the situation is updated in near or real-time on different presentation areas, it will be possible to engage targets with increased precision. Since all entities will be fully connected, it also provide new and flexible ways of organizing to achieve an objective or the general goal. The network also is considered to admit implementation of less hierarchical organizations. Furthermore, since all units will have the same understanding and awareness of the situation, lower levels of command will have freedom to decide to self-synchronize. Using an approach like this to locally utilize available resources is considered contributing to that an objective is reached faster and more efficient despite an earlier directive from higher levels of command. Given that the characteristics of future technology and that adequate models of future C^2 conditions are available, the overall research question of this thesis is:

Q Are the claims, made by the ROLF 2010-vision and the concept of NCW, about the assumed beneficial effects of future technology actually valid?

The following prerequisites were found necessary to tackle when considering this overall research question:

- To create a basic understanding, of how people organize and exercise C^2 under conditions where "future technology" is available.
- To develop methods for both observation and measurement of C^2 performance under controlled conditions, where selected claims and assumptions made by the ROLF 2010-vision and the NCW concept can be put up to test.

1.3 Applied perspectives on C^2

Besides the overall research question, the thesis is based on the following general assumptions expresses in the literature (Alberts, Garstka, & Stein, 2000; Potts, 2003; Sundin & Friman, 1998):

– A widespread opinion in many C^2 establishments is that success in the future control of dynamic systems will be dependent on the ability to quickly understand the situation to be able to control it. This is supposed to be achieved by what is referred in the literature as obtaining "information superiority" (e.g., see Potts, 2003). By having such means it is suggested that they will provide a capability to be ahead of an opponent in understanding and making decisions about the current situation.

- For personnel executing C^2 it is assumed that presentation of data and information must be timely, highly customizable, and changeable for being adequate. In addition, assumptions are made that novel technological solutions will increase cooperation and interaction among the personnel. By providing new means for presenting, visualizing, and interacting with data and information the shared or common understanding of a current situation will become enhanced. Moreover, new technologies will admit that much of C^2 work will become facilitated by automation.
- Technology will provide possibilities for new command and control concepts. Such concepts can be used to exploit synergies arising from how to utilize available assets; by extended means of communication between participants; and by capabilities to implement new forms of organizations. Accordingly, it is assumed that novel or future technology will support utilization of resources more effectively.

1.4 Scope and delimitation

The environment that decision-makers on different levels of command have to handle when exercising C^2 under a crisis situation or a military operation usually is characterized by its dynamic development, potential dangers or threats, time-pressure, and uncertainties of how the situation will develop.

Within the scientific community studying military C^2, assumptions are made where introduction of ICT with novel properties will improve the performance of how C^2 is exercised under such situations. This also has led to assumptions regarding both the design of the physical C^2 working environment and how data and information preferably should mediated, communicated, presented, and represented. Moreover, providing data and information in real or near real-time is assumed to bring benefits to the awareness and the assessment of a current situation. In addition, introduction of novel ICT capabilities is assumed to contribute to new and more efficient forms of organizations, which will improve the ability to solve a general task or aim.

The scope of this thesis is to critically dissect and assess *selected* assumptions outlined above by empirical studies. However, since the empirical studies in this thesis are based on assumed properties of technologies that are not available in natural C^2 settings, these studies are undertaken in a laboratory environment. The focus of this work is initially to study and understand how C^2 work is performed by a decision-making team where characteristics and means of future ICT are available as assumed by the scientific community of military C^2. From that, experiences are used to examine and develop tools and methods for experimental studies, measurement, and evaluation of C^2 performance where decision-makers are supported by technologies with future characteristics.

2. Context of the research

I believe also that he will be successful who directs his actions according to the spirit of the times, and that he whose actions do not accord with the times will not be successful. Because men are seen, in affairs that lead to the end which every man has before him, namely, glory and riches, to get there by various methods; one with caution, another with haste; one by force, another by skill; one by patience, another by its opposite; and each one succeeds in reaching the goal by a different method.

The Prince
Machiavelli

2.1 The emergence of the NCW concept

From the aftermath of the United States victory in the 1991 Gulf War against Iraq, Osinga (2010, p. 21) stress that the US military and its industrial suppliers set out to conduct experiments and concept development with the aim to fully exploit technological advances that operation "Desert Storm" foreshadowed, and write that the:

> [p]rime objectives were to make the battlefield more transparent, to achieve "information dominance" and create situational awareness at all command levels, to disseminate target information in a timely manner to those who needed it, and to adjust command and control doctrine accordingly. The objective was to shorten the "sensor-to-shooter" time, and to improve responsiveness.

With this background, the lines of thought behind the so called revolution in military affairs (RMA) and later the concept of NCW emerged in the United States. The ideas behind NCW were not an isolated phenomenon for development of the US Armed Forces and its C^2 doctrines. Most Western countries had its counterparts, so also Sweden and, for example, Norway with their aim of transforming their Armed Forces to a network based defence (NBD)[1], and the UK Defence transformation against network enabled capability (NEC) (e.g., see Farrel, 2008; Försvarsmakten, 2002; MoD, 2003; Prop. 2001/02:10, 2001; Prop. 73 S (2011-2012), 2011).

[1] *In Swedish* – nätverksbaserat försvar (NBF), and *in Norwegian* – nettverksbasert forsvar (NbF)

In an article by Cebrowski and Garstka (1998), a decisive shift in the theory and practice of warfare is presented that became an important contribution for the development of NCW. NCW is presented in contrast to the current "platform centric warfare (PCW)" which has dominated warfare throughout the 20th century.[2] PCW is characterized by its design to support industrial-age organization and processes. This has led to rigid, top down hierarchical organizations emphasizing centralized planning and coordinated execution across a coherent battle front. In addition, PCW information architectures are characterized by e.g., hierarchical information flows, voice communications, limited interoperability, and stove-piped C^2 systems (Alberts, Garstka, Hayes, & Signori, 2001; Alberts et al., 2000). Thus, systems that are engineered according to the principles of PCW often implies that communication between different platforms' C^2 functions is difficult, if even possible. From this follows also that it can be difficult to achieve synergy effects between different platforms. An example where such synergy effects could emerge is when one platform can use and combine its own sensor data with another platform's sensors to improve its assessment and awareness of a situation. However, since most platforms and C^2 systems are specialized for their specific purpose, such possibilities of data exchange is rare. In addition, to prevent that different platforms engage each other by accident it is often necessary to divide their areas of responsibilities—geographically and/or in time (e.g., see Owens & Offley, 2000, p. 89-94).[3] From an analogy of how multinational enterprises compete on the market, Cebrowski and Garstka (1998) develop and apply a perspective whereby the NCW concept grows from society and societal changes. By comparing contemporary Information Age concepts, co-evolving business processes, economics, and organizations with the military, they stress that battle time plays a critical role and thus is analogous to the new and time competitory economic model. Hence, the ideas behind the NCW concept are intertwined with theories and ideas for everything between advances in ICT to the debate of societal changes due to our way of entering the so called Information Age (e.g., see Castells, 1997, 1998, 2000; Evans & Wurster, 2000; Groth, 1999; Schrage, 1995; van Alstyne, 1997; Webster, 2006). Furthermore, by implementing NCW Cebrowski and Garstka (1998) argue that it will allow development of increased speed of command and enable forces to organize from bottom-up by self-synchronization to meet the commander's intent. Later a widely accepted definition of NCW is provided by Alberts et al. (2000, p. 2):

[2] A platform in the military context can be any military structure or vehicle that bear weapons.

[3] The PCW concept is still persistent in the SweAF while writing this in 2014. The objectives described in the ROLF 2010-vision, the NCW, and the NBF concepts are not achieved. However, the capabilities and overall goals strived for in these vision and concepts are comparable with the current Swedish concept of "war-fighting with integrated systems" (HKV, 2013).

> We define NCW as an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization.

Beside the development of ICT, Osinga (2010, p. 20-23) identifies two additional streams of technological advances that contribute to the NCW effort. Namely, on the one hand surveillance and sensor capabilities, and on the other hand the ability to hit targets precisely and quickly. The emphases where assumed possibilities of contemporary and future ICT form a significant role seem, however, to stand out as predominant. Accordingly, military theorists and advocates for NCW suggest that the concept with networked C^2 architectures will increase connectivity between organizational assets. Thus, information delays will be reduced that will contribute to increased speed of command and the tempo of future military operations. However, this presumes that both central and local levels of command are connected by networked C^2 architectures and simultaneously have access to the same data and information from different sensors and databases with support from ICT (Alberts et al., 2001; Alberts et al., 2000; Alberts & Hayes, 2007; Arquilla & Ronfeldt, 2000; Cebrowski & Garstka, 1998; Potts, 2003). In Persson and Johansson (2001) a comparison between the characteristics of traditional PCW and envisioned NCW C^2-systems is discussed (table 2.1). Aside from that the table shows that the differences between the two concepts are significant it also outline the main characteristics of future technologies. In addition, these characteristics are used to guide development of new C^2-systems based on the underlying thoughts of NCW. Whereas NCW can be regarded as a conjecture or theory of future C^2, it also has to be instantiated in a form that reflect its characteristics and claims more in detail. In Fewell and Hazen (2003, p. 4-26) a hierarchical arrangement of the NCW characteristics is suggested to consist of five levels. These levels depend only on those at the same level or lower in the hierarchy (table 2.2).

Historically, the design of military C^2 systems has been formed by the development of warfare from the start of the 19^{th} century. At the time, changes in conditions for warfare created a problem of information delays where commanders on central levels became unable to maintain an adequate appreciation of the tactical situation. Accordingly, real-time command became a practical impossibility (K. G. Stewart, 2010). The definition of NCW and its objectives suggest that ICT will provide all levels of command with the same data, information, and knowledge in real or near real-time of an operation.

Hence, following the concept of NCW, utilization of future ICT gives promises to bridge the problem of information delays on central levels of command. Accordingly, it seems that the NCW application of ICT again will provide means for central levels of command to exercise or directly influence

Table 2.1. *Characteristics of traditional C²-systems compared with envisioned C²-systems. Adapted from Persson and Johansson (2001).*

"Traditional" C²-systems	Envisioned C²-systems
• Organised in hierarchies. • Information distributed over a variety of systems, analogue and digital. Most common medium is text- or verbal communication. • Data is seldom retrieved directly from the sensor by the decision-maker. It is rather filtered through the chain of command by humans that interpret it and aggregates it in a fashion that they assume will fit the recipient. • Presentation of data is handled "on spot", meaning that the user of the data organises it him/her self, normally on flip-boards or paper-maps. The delay between sensor registration and presentation depends greatly on the organisational "distance' between the sensor and the receiver	• Organised in networks. • All information is distributed to all nodes in the system. Anyone can access data in the system. • Powerful sensors support the system and feed the organisation with detailed information. • Data is mostly retrieved directly from sensors. Filtering or aggregation is done by automation. • Presentation is done via computer-systems. Most data is presented in dynamic digital maps. The time between data retrieval and presentation is near real-time. • It is possible to communicate with anyone in the organisation, meaning that messages do not have to be mediated via different levels in the organisation.

Table 2.2. *The characteristics of a network-centric military system arranged as a hierarchy. Adapted from Fewell and Hazen (2003).*

Top level—force-level characteristics: • speed of command • self-synchronization • effects-based operations • information superiority • force agility and massing of effects • shared situational awareness • reachback • interoperability
Second level—characteristics of decisions: • speed • soundness
Third level—characteristics of information: • relevance • clarity • accuracy • comprehensibility • value • timeliness • consistency • secrecy • degree of interoperability • age, currency • completeness • authenticity
Fourth level—general characteristics of networks: • availability • reliability • concurrency • survivability • coverage, homogeneity • security
Base level—physical properties: Bandwitdth, network topology, server speed, etc.

C² on subordinate (tactical) levels. However, NCW also aims for subordinate (tactical) units to freely act and coordinate themselves upon a situation without having to obtain approval from above as long as the purpose of the activities meet the superior commander's intent. Thus, the philosophy behind NCW seems to provide means where the exertion of C^2 can stretch all between highly centralized or decentralized C^2.

2.2 Early Western military C^2 as a scientific issue

Military C^2 has been a subject for scientific investigation and explanation at least since the 18^{th} century. For example, Starkey (2003) write that Henry Humphrey Evans Lloyd (1720-1783) added a serious study of contemporary military thought and practice coupled with a wide reading of Enlightenment literature. Lloyd's military principles combine the influence of Helvétius and Rousseau with that of Saxe and Frederick the Great. Lloyd's conclusion was that a war of position was preferable to battle. Exactly knowing the country, the science of position, camps, and marches were the essential disciplines to be mastered by a general. Starkey (2003, p. 57) quote Lloyd (1781) that the principles allow to:

> [reduce military operations to geometrical precision, and may for ever make war without being obliged to fight. Marshal Saxe calls battles the resource of ignorant generals; when they do not know what to do they give battle.] Lloyd's introduction to his principles describes war as a branch of Newtonian mechanics: [War is a state of action. An army is the instrument with which every species of military action is performed; like all machines it is composed of various parts, and its perfection will depend, first on that of its several parts; and second, on the manner in which they are arranged; so that the whole may have the following properties, viz., strength, agility, and universality; if these are properly combined the machine is perfect.]

Furthermore, Starkey (2003, p. 60) put forward that Lloyd's ideal army was one inspired by liberty and an army in which careers were open to merit. In this sense, Lloyd pointed toward a new era in warfare. The writings of Lloyd as well as Dietritch Adam Heinrich von Billow (1757-1807) were aimed to "find a set of 'rational principles based on hard, quantifiable data that might reduce the conduct of war to a branch of the natural sciences […] from which the play of chance and uncertainty' could be entirely eliminated" (Watts, 1996, p. 22). Thus, this aim of reducing uncertainty on the battle field has been persistent and is equally topical today as it was for more than 200 years ago.

2.3 Some contemporary views of military C^2

The emergence of a modern science of C^2 is a very young field of research. The concept was introduced some twenty years ago by the *Armed Forces Communication and Electronics Association (AFCEA).* At the time, it was an umbrella term of research conducted with the purpose to provide a foundation for new computer supported C^2 systems that began to emerge. As put forward by Brehmer (2008c), no direct role models in the higher education system for C^2 science have existed in Sweden or abroad. Its roots can be derived from the pioneering work provided and published by AFCEA (Johnson & A. H. Levis, 1988, 1989; A. H. Levis & I. S. Levis, 1994). In addition, Brehmer (2010) observe that there is a large amount of studies on C^2; however, with some exceptions these tend to be concerned with aspects of C^2 instead of with C^2 viewed as a whole. From subsequent development of ICT and that the sociotechnical nature of exercising C^2 has become more apparent, the need of developing C^2 science and a general theory of C^2 has increased. As suggested by Builder, Bankes, and Nordin (1999, p. 13), a comprehensive theory of C^2 should not only be able to explain how to organize, connect, and process information, it should also:

– explain how the quality of commanders' ideas and the expression of those ideas can be assessed and, indeed, duplicated;
– explain how C^2 systems, including commanders, should work, and the ideal circumstances in which that work can occur;
– provide measures of performance for commanders and their staffs, as well as for the communications and computers that support them.

A variety of perspectives have been given to develop a C^2 science and theory for current and future needs. For example, Skyttner (2005b) argue that earlier C^2 was regarded as part of traditional military theory, often denoted as "the art of war." and writes (p. 1244): "As an art, it can only be developed and reach its fulfilment inside the born leader with his special creativity, intuition capability and the divine vestige, existing in very few persons." Accordingly, this view implies consequences both for education of commanders and scientific inquiries. In the first case, Skyttner (2005b) stress that the number of individuals with these abilities is too few to supply the demands from society. In the second case, solutions based on the traditional view often are seen without either theories or scientific method. To deal with this situation, Skyttner (2005b) propose development of C^2 science that is founded on general system theory (GST).

One perspective on C^2 that has influenced, restricted and guided this thesis largely, both as science and as an evolving theory, is the framework being developed within the research projects conducted at the SNDC Command and Control Studies Division. Since the research in this thesis is framed within this perspective, it has to be regarded as both directive as well as natural. The foundation for this perspective and its viewpoints are discussed by Brehmer (2005b, 2006, 2007b, 2008a, 2008c, 2009, 2010, 2013). In contrast to Skyttner (2005b), Brehmer (2008c) argue that C^2 viewed as a professional activity demands "art" by its practitioners, as well as a scientific foundation. Furthermore, that the aim of C^2 science is to create conditions for a more efficient practice of C^2. From this viewpoint, scientific progress and results transferred to education will ultimately play a major role. Thus, at a first glance these two author's views on how to develop a suitable C^2 science seem to diverge. However, both authors are referring to and advocate a system view on the field of C^2, which also with some respect bring their point of views together. Below, Brehmer's and some additional perspectives and viewpoints of C^2 as an emergent modern science and theory are presented (section 2.6 and forward). However, first a perspective on the meanings of "command," "control," and "command and control (C^2)" are introduced.

2.4 Connotations of "command", "control", and "C^2"

Unlike the Swedish or the German languages where one word is used for the field of C^2, viz., "ledning" and "Führung," Anglo-Saxon languages use a composition of two words; "command" and "control." Holley (1988) put forward that, in its most basic sense, command involves perceiving, assessing and deciding upon a situation. Control, on the other hand, involves the communication of the commander's decisions to subordinate levels of command and to continuously monitor those to ensure compliance. In addition, monitoring also includes coordination of diverse elements and to perceive the need to alter the previous decisions due to changes in the situation. However, Holley's perception of the terms relative meaning is just one of many. A condition which has led to a problem, or at least discussions, to sort out their connotations within the field of C^2 science.

Pigeau and MacCann (1995) put forward that the case of indistinct meaning of the terms and that their definitions can be contradictory might have contributed to poor design of C^2 support systems. Pigeau and MacCann (1995) argue that development of new C^2 systems in all essentials has been focused on the "control" aspects in the process of exercising C^2. Accordingly, it has become a matter of bringing in automation of different procedures. However, it is essential that C^2 is considered as a human centered activity for C^2 to be effective (Pigeau & MacCann, 1995). In addition, that the human component has been under-emphasized and under-researched led to a condition of frustration, which can be illustrated by the remarks provided in Pigeau and MacCann (2000, p. 181):

> Both the scientific and the military communities continue to be frustrated about the state of command and control theory and C^2 systems development. Major advances in information technology and in weapons delivery have certainly changed C^2's face and pace, but these changes have occurred within a philosophical and conceptual vacuum. Those responsible for "doing" command and control are increasingly burdened by a dizzying array of operational commitments, with only confusing concepts and poorly designed systems to help them. It is a tribute to human fortitude and determination that our militaries are as successful as they are.

From an analysis of different concepts and definitions of "control," and "command," Pigeau and MacCann (2002, p. 56) re-conceptualize the meaning of the terms and suggest the following definitions to overcome the problems above: *control*—[are] those structures and processes devised by command to enable it and to manage risk; and *command*—[is] the creative expression of human will necessary to accomplish the mission. By these definitions, MacCann and Pigeau (1999) propose an additional definition of C^2 that is centered on the human idea of "intent," viz., to accomplish an aim or a purpose with some activity, where *command and control (C^2)*—[is] the establishment of common intent to achieve coordinated action. Among several implications that follows from Pigeau and MacCann's (re-)conceptualization of "command" and "control", is that (Pigeau & MacCann, 2002, p. 62):

> Command and control are complementary. Command cannot be exercised without control, but control is meaningless without command. However, the two are not equal. Command creates and changes the structures and processes of control to suit the uncertain military situation, thus making command pre-eminent. Control should always be subordinate to command.

In addition, the authors make a distinction between on the one hand their concept of control and on the other hand the concept of control in the cybernetic sense which involves feedback mechanisms. Pigeau and MacCann (2002, p. 54) stress that control in militaristic terms implies more; e.g., the personnel, facilities and procedures for planning, directing and coordinating resources in the accomplishment of the mission. The arguments that the authors express regarding the feedback function often needed when exercising C^2; however, do not provide more clarity to solving the problem. Instead, it seems to contribute to the confusion that they aim to criticize.

The emergence and development of a commander's intent is a basic idea in the conceptualization of human centric C^2. MacCann and Pigeau (1999, 2000) take the concept further by their definition of C^2 when introducing the concept of "common intent" and by dividing intent to be either explicit or implicit. The concept of *explicit intent* corresponds to the part of intent that is made publicly available through orders, briefings, questions and discussions. Considering *implicit intent*, it corresponds to the part of intent that derives from personal expectations, military training, tradition, ethos, and from deep cultural values. According to Pigeau and MacCann (2000, p. 172) *common intent* is considered as the sum of shared explicit and implicit intent.

While further exploring the suggested distinctions between explicit and implicit intent, explicit intent is possible to express and reflect in different physical forms and to communicate in public. Implicit intent is created by a larger body of different forms of social constraints and assumptions that intend to support explicit intent. The conditions forming implicit intent are dependent on characteristics that are experienced as natural in a national or cohesive force. However, intents with such dependencies and characteristics can be difficult, if even possible, to communicate under conditions where forces are temporary composed. An example of that could be when coalition forces are put together under tight time conditions to conduct a joint military operation (e.g., see Pigeau & MacCann, 2000, figure 2, p. 166). Accordingly, under some conditions it might be problematic to accomplish a common intent.

Also Pigeau and MacCann stress that their concepts are not a theory of C^2, but a framework offered to provide a unifying construct for discussing, exploring, and explaining C^2 (MacCann & Pigeau, 2000; MacCann, Pigeau, & English, 2003; Pigeau & MacCann, 2002). However, the arguments by Pigeau and MacCann (2002, p. 56) implies that the framework does not limit command only to commanders. That since any human is capable of command and—"all humans are inherently capable of creatively expressing their will." Hence, it seems possible to utilize the framework in a wide spectrum and in all levels of command of a future science and theory of C^2. Furthermore, the context represented by the above framework for C^2 also provides a basis for development of hypotheses related to the phenomena derived from statements of command and control, and processes of commanding and controlling.

2.5 Boyd - a source of inspiration for contemporary theories of C^2

Although John Boyd (1927-1997) never was published, his legacy has provided an important contribution and inspiration to contemporary development of C^2 theory (Boyd, 1976a, 1976b, 1982, 1987a, 1987b, 1992, 1995).[4] However, as noted in Osinga (2005) and in Brehmer (2008b), Boyd is often quoted, but few seem to have acquainted themselves with his work to achieve a deeper understanding of his thoughts. Accordingly, both Osinga (2005) and Brehmer (2008b) present analyses of Boyd's thoughts. In Osinga's case, Boyd's thoughts are applied on strategic analysis, and Brehmer show how they can be applied when exercising C^2.

[4]The writings and the presentations left by Boyd to the military community can be acquired at http://dnipogo.org/john-r-boyd/

If people know anything about Boyd, it generally has something to do with the simplified "OODA-loop," which acronym represents "observe, orient, decide, act" (Osinga, 2005). Moreover, the OODA-loop is often depicted in a simple sequence, as if the acronym stood for "observe, then orient, then decide, then act" (figure 2.1).

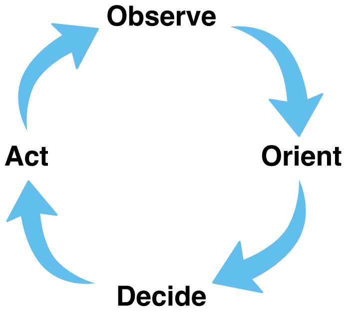

Figure 2.1. The simplified OODA-loop.

Although Boyd developed a more comprehensive model of his thoughts, he probably always will remain associated with the popular interpretation of the simplified OODA-loop (Osinga, 2005, p. 6). The simplified OODA-loop suggests that success in war depends on the ability to out-pace and out-think the opponent, or put differently, on the ability to go through the OODA cycle more rapidly than the opponent. The study of conflict is thus reduced to dueling OODA-loops, with the side that can go through its loop the more quickly building a competitive advantage. For a further discussion on Boyd's more comprehensive OODA-loop and its applications on C^2, e.g., see Brehmer (2005a, 2005b, 2006), Richards (2004), and Osinga (2005).

2.6 Perspectives of C^2 viewed as science and as system design

By considering C^2 as a human activity aimed to solve problems, Brehmer (2010, 2013) argues that C^2 is concerned with design and execution of courses of action to achieve (military) goals. Hence, Brehmer (2010, 2013) propose that the study of C^2 should be positioned among the sciences of the artificial as suggested by Simon (1996). Furthermore, by an additional observation where C^2 always is conducted within and shaped of a C^2 system, Brehmer (2010, 2013) stress that the term "C^2 system" should be taken in the widest possible sense. Accordingly, a C^2 system includes both available technologies and equipment, individuals, organization, methods, and organization of work, etc. Using this as a point of departure, Brehmer (2010, 2013) put forward that to understand and to evaluate C^2 it becomes a matter of understanding and evaluating the C^2 system viewed as a whole. Acknowledging that a C^2 system is an artifact, it thus could be understood in the terms of its purpose and by the logic it was designed (Brehmer, 2007b, 2013).

From the writings of Simon (1996) and an adaption of Rasmussen's abstraction hierarchy (Rasmussen, 1983, 1985), Brehmer suggest an approach based on *design logic*, which implies an analysis in terms of three basic levels. The highest level is *purpose* and answers the question "why" a C^2 system exists or should be constructed. Brehmer's (2007, p. 213-214) answer to that question when designing military C^2 systems is "to provide direction and coordination [of a] military effort." The next level is *function* and answers the question "what" must the C^2 system do to fulfill its purpose. The final level is *form*, which answers the question "how" the functions of the C^2 system are fulfilled (Brehmer, 2007b, p. 212; also see Brehmer, 2010, 2013). Furthermore, applying these three conceptual levels for design of a C^2 system, it is conducted as a *top-down* process that answers specific questions of the artifact of interest. While considering or conducting an analysis of an existing C^2 system the process is however, reversed. Under such conditions the process is thus conducted *bottom-up*. The process of design logic suggested by Brehmer (2013) is portrayed in figure 2.2.

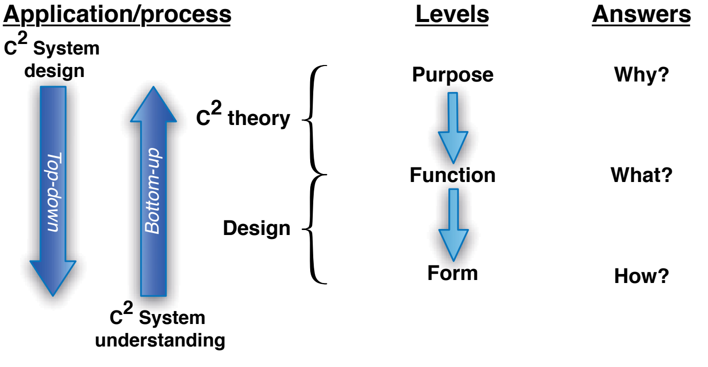

Figure 2.2. Design logic and its three basic conceptual levels. The direction of the left arrows depends on the problem of which the design logic is applied. Design of e.g., a C^2 system is a top-down process, but understanding an existing C^2 system in terms of the logic of design is a bottom-up process, where the functions are induced from the "form". *Illustration acquired and modified from Brehmer (2010) with kind permission by the author.*

2.6.1 The DOODA-loop

Furthermore, the model should be considered as a recursive system with Dynamic Observe, Orient, Decide, Act (DOODA)-loops above and beneath the DOODA-loop in focus. The DOODA-loop model is one of many examples of cybernetic models of C^2; however, Brehmer (2009, p. 59) stress that it differs from other models in that the DOODA-loop has its origin in what people actually do when exercising C^2, and not from a general reasoning about [automatic] control. Applying the concepts outlined above on C^2 science implies both methodological considerations and how C^2 research can improve military C^2. As Brehmer (2009, p. 60) points out—C^2 can be observed from three different perspectives of how C^2:

1. *actually is and has been exercised* – This aspect of C^2 studies can be categorized under *descriptive science of C^2*. Such studies can be historical, but can also apply to studies that describe how C^2 is exercised in contemporary armed forces.
2. *could be exercised* – This aspect of C^2 studies can be categorized under *theoretical science of C^2*. This category may have its greatest expression in the work of developing new C^2 systems.
3. *should be exercised* – This aspect of C^2 studies can be categorized under *normative science of C^2*. It consider how a given goal should be achieved by the practice of exerting C^2. This kind of studies primarily occur under doctrinal work. In terms of DOODA, research on this level primarily concern the purpose of understanding functions needed to achieve successful C^2.

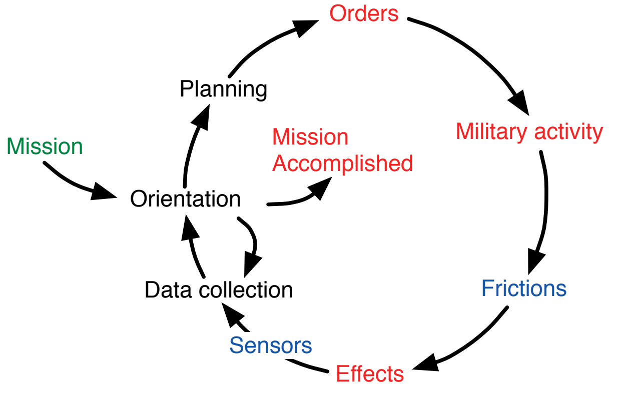

Figure 2.3. The DOODA-loop. Green indicates input, black functions, red products, and blue “filters”. *Adapted and modified from Brehmer (2013) with kind permission from the author.*

Brehmer (2013, p. 61-63) argues that of primary interest here is theoretical science of C^2, which assumes several preconditions for what is required for successful and efficient C^2. Whereas the orient function[5] is concerned with the *what* and planning is concerned with the *how* is to be considered as a typical example. Thus, Brehmer (2007b) stress that the proposed functions needed for C^2 are not carved in stone, but what is necessary is to distinguish between function and process. Furthermore, hypotheses can be developed on basis of presumed assumptions. An evaluation of this aspect of C^2 science must be conducted on two levels. First, if the system in focus, for example an information system, is working as planned. Second, an evaluation must be conducted under practical use to determine whether the desired effects are achieved or not (Brehmer, 2009).

Following Brehmer's argumentation from earlier publications of dynamic decision-making (e.g., see Brehmer, 1992) until recent, it can be considered as straggly. From an initial focus where *processes* of decision-making should guide C^2 system design it slips to consider C^2 as an *activity* supported by functions and that a C^2 system should be evaluated as a whole (e.g., see Brehmer, 2006, 2009, 2010, 2013). For example, in Brehmer (1992, p. 213) it is stated: "[…] both the system that the decision maker seeks to control and the means that he uses for control must be seen as a process." This can be compared with the later statement in Brehmer (2010): "*C2 is a human activity that aims at solving (military) problems.* Put differently, C2 is concerned with *design and execution of courses of action* to achieve (military) goals. This is what positions the study of C2 among the sciences of the artificial" [emphasis in original]. Unfortunately, this shift in focus is not clarified. One plausible explanation can be that earlier studies are focused on a decision-maker as an individual. Hence, the problems and phenomena that are studied are related to *individuals* and their cognitive processes and performance when handling dynamic events. By later using a perspective from which C^2 is composed as a complex sociotechnical system, it implies that considerations have to be taken to the C^2 system viewed as a whole. Accordingly, from the change of perspective the shift to consider C^2 as a superior or overall activity might have occurred as a natural consequence. Moreover, although Brehmer write about different levels of C^2, he neglects to mention the recursive or redundant properties of the C^2 system he illustrate by his DOODA model. For a complementary perspective and reasoning about recursiveness and redundancy of potential command, see Beer (1966, 1979, 1981).

[5]In publications before Brehmer, B. (2013). *Insatsledning: Ledningsvetenskap hjälper dig att peka åt rätt håll.* Stockholm: Försvarshögskolan, the "orient function" was labelled "sensemaking."

2.6.2 C^2 from a joint cognitive system perspective

An additional approach to C^2 is the *joint cognitive system (JCS)* paradigm introduced by Hollnagel and Woods (2005). Although the authors do not explicitly claim that their contribution is a science or theory of C^2, their concept includes elements that are relevant for developing the field (e.g., see Stanton, Baber, & Harris, 2008). The paradigm stem from the field of cognitive systems engineering (CSE) and imply that the unit of analysis is a JCS. According to Hollnagel and Woods (2005, p. 22), the definition of a JCS is; "a system that can modify its behaviour on the basis of experience so as to achieve specific anti-entropic ends." From this follows that a JCS is defined by what it *does* and that it can *control* what it does. Furthermore, from the view of CSE follows that it also is important to understand *why* a JCS does what it does. In addition, the reasoning is based on a pragmatic definition of cognition, which not defines cognition as a psychological process unique to humans. Instead, cognition is viewed as characteristic of system performance—the ability to maintain control. Hence, any system that can maintain control is therefore potentially cognitive or has cognition, which also refers to JCS as a whole and independent of if they are biological individuals, artificial intelligences, or organizations (Hollnagel, 2003, p. 7).

In Hollnagel and Woods (2005), the *Contextual Control Model (COCOM)* is presented (figure 2.4). The model is based on cognitive modes and aimed to explain the effects of the context in which people perform their actions. It is possible to combine COCOM and Hollnagel's (2007) perspective on decision-making to the concept of C^2. From this follows that exerting C^2 is not a pre-defined sequence of events that follow a procedural pattern, viz., as a process. Instead, exerting C^2 is viewed as a series of actions that are determined by the context and the facet of work. When an action is taken in COCOM, it implies that the action is determined by the context, and next action is determined by the current context and the competence that the JCS possess and apply to handle the situation. According to (Hollnagel, 2007), a JCS ability to maintain control depends on the controlling system's interpretation of events and selection of action alternatives. Hence, the set of patterns of behavior is reflective of the environment and the cognitive goal(s) of a JCS, both of which contain variety. The ability to control is obtained by the three main elements that constitute and are provided in COCOM (Hollnagel & Woods, 2005, p. 145):

- *Competence*, which represents the set of possible actions that a JCS can apply to a situation to meet recognized needs and demands.
- *Control*, which characterizes the orderliness of performance and the way in which competence is applied.
- *Constructs*, which refer to the description of the situation used by the [JCS] to evaluate events and selected actions.

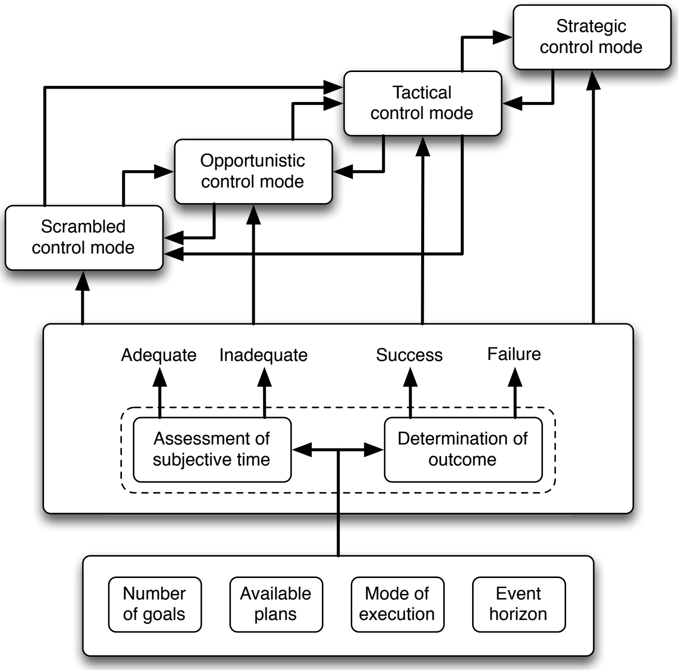

Figure 2.4. Hollnagel's contextual control model with its four modes of control. *Adapted and modified from Stanton, Baber, and Harris (2008).*

As pointed out in (Hollnagel & Woods, 2005, p. 145), an essential part of control is planning within a system's time horizon. These activities lead to a sequential description of possible actions that either can be constructed or predefined depending on the context. The conduct of such work is not explicitly expressed in COCOM; however, possible to refer to by the notion of "command" described in section 2.4 above. Furthermore, it is possible to find similarities between Hollnagel's line of thought and the concept of dynamic decision-making proposed by Brehmer (e.g., see Brehmer, 1992). Although the authors' perspectives differ in several ways, both authors emphasize the importance to consider time under decision-making. However, Hollnagel (2002) illuminate and make a more thorough discussion regarding time and its consequence for decision-making under different situations. For example, whether available time is sufficient or not for a JCS's ability to take appropriate actions under a current situation. Whereas available time is an important matter for a system's ability to uphold control, it also is bounded to the four modes of control proposed in Hollnagel (2002, p. 148-149) and Hollnagel and Woods (2005, p.146-147):

1. *Scrambled Control* – This control mode borders on the extreme condition of zero control and is characterized by a situation where next action is unpredictable or random. The role of cognition or reflections are minor, which corresponds to a trial-and-error type of performance that is typically the case when people act in panic. Accordingly, there is little or no correspondence between the situation and the actions.
2. *Opportunistic Control* – Under this control mode, next action reflects the prominent features of the current context. Only little planning or anticipation is involved. Either because the context is ambiguous or because the situation is chaotic. Because of constraints such as lack of time, knowledge, experience, or expertise, activities are taken by chance.
3. *Tactical Control* – This control mode is characterized by pre-planned activities over a limited time, and sometimes planning also is *ad hoc*. To plan and fulfill short time actions, known rules and procedures are used.
4. *Strategic Control* – This control mode is characterized by focus on higher-level goals and long term planning. Execution of control on the strategic level is influenced by available knowledge, skills, expertise, and the overall situation. Accordingly, performance is less likely to be influenced by sudden changes of the situation or in the environment.

Both Brehmer and Hollnagel emphasize the importance to consider time in their models. To also describe multiple levels of performance over time; however, Hollnagel and Woods (2005, p. 149) present an extended version of the COCOM model that accordingly is called the *Extended Control Model (ECOM)*. Hence, ECOM also considers an illustration of subordinate levels' decision-cycles and their relation to different forms of control, but is also applicable on command as indicated above. From the ECOM model it is possible to illustrate and explain time lags resulting from so called "frictions" that emerges on lower levels of command, but might have effect on how a situation develop. Unfortunately, these considerations are absent in Brehmer's model, at least in an explicit way.

2.7 Summary

Above, the context of the research in this thesis has been presented. The scientific field of military C^2 has been exemplified by contemporary views articulated by several researchers. From this; however, it can be concluded that a scientific theory of C^2 is absent, at least from providing inferential power that meets Popper's proposal to adopt falsifiability as criterion for deciding whether a theoretical system belongs to empirical science or how it withstands tests (Popper, 1959, pp. 78, pp. 251). Accordingly, the proposals made cannot be considered to provide a formal theory of C^2. Instead, the proposals for a theory of C^2 seem still be in its infancy, providing frameworks that can be developed to a theory of C^2 in the future. Furthermore, contemporary proposals are characterized by assumptions made for the future. They also put a lot of faith in networked solutions, together with being technology oriented. Considering models of C^2, they can be regarded as too general. However, they serve a purpose by providing guidelines for research during different stages, or processes, when exercising C^2. Furthermore, they can give support for both explanatory purposes for and design guidelines of C^2-systems.

3. Theoretical frameworks for the research

Do not be afraid of the word 'theory'. Yes, it can sound dauntingly abstract at times, and in the hands of some writers can appear to have precious little to do with the actual, visual world around us. Good theory however, is an awesome thing. [...] But unless we actually use it, it borders on the metaphysical and might as well not be used at all.

Richard Howells
Visual Culture

In the following chapter, I provide the theoretical frameworks used in this thesis. My view on theory can of course be derived from my academic origin in systems science and informatics. In addition, I have a pragmatic view on theory where four desirable attributes can be identified for a theory. First, it requires descriptive power, which provides a conceptual framework that support a sensible description of the world. Second, it needs rhetorical power providing important aspects of the conceptual structure and how these maps to the real world. The third attribute is inferential power, which may lead to insights for, for example, design of C^2 systems. The final attribute considers application of the theory for essentially pragmatic reasons. This translate to the need of informing and guiding system design at the right level of analysis to bridge the gap from description to design (Halverson, 2002, p. 243-244).

3.1 HCI and CSCW

A young scientific field that provides guidelines and solutions for design of computer artifacts is human computer interaction (HCI). HCI has its roots in human factors and cognitive psychology, with study of the interaction between human and computer and especially to the human's use of the computer. An earlier name for the field was man-machine interaction, where a person, or a human usually was replaced by the term "user" (May, 2001). In its broadest sense, HCI is what happens when a human user and a computer system get together to accomplish something (Hartson & Pyla, 2012, p. 9). Accordingly, HCI research aims for improving the interaction between users and computing devices. Viz., to provide means to develop usable systems. Here the concept of usability plays a significant role. However, as pointed out by Carroll (2013) the concept of usability has been re-articulated and reconstructed almost continually within HCI. Therefore, it also has become increasingly rich and intriguingly problematic. Nevertheless, the definition suggested by Shackel (2009) captures not only a systems ease of use but also its effectiveness in terms of measures of performance (Shackel, 2009, p. 340):

> [T]he capability in human functional terms to be used easily and effectively by the specified range of users, given specified training and user support, to fulfil the specified range of tasks, within the specified range of environmental scenarios.

This definition also have its equivalent within design science and its desire to guide improvements when introducing new and innovative artifacts. However, the results from introducing new technology is not always obvious. Therefore it is important to understand whether an artifact provide the improvements wished for and to find valid measures that can be utilized to evaluate to what degree the improvement have been achieved (Hevner, 2007; Hevner, March, Park, & Ram, 2004; Simon, 1996). For this purpose Shackel (2009) define and provides operational criteria of how usability can be specified and measured.

Table 3.1. *Definition of usability proposed in terms of goals and operationalized criteria. Adapted from Shackel (2009, p. 341).*

Effectiveness	• The required range of tasks must be accomplished at better than some required level of performance (e.g., in terms of speed and errors) • by some required percentage of the specified target range of users • within some required proportion of the range of usage environments
Learnability	• within some specified time from commissioning and start of user training • based upon some specified amount of training and user support • and within some specified relearning time each time for intermittent users
Flexibility	• with flexibility allowing adaptation to some specified percentage variation in tasks and/or environments beyond those first specified
Attitude	• and within acceptable levels of human cost in terms of tiredness, discomfort, frustration and personal effort • so that satisfaction causes continued and enhanced usage of the system

Currently, HCI is developing towards a multidisciplinary field of science that merges several aspects of different research areas, such as scientific visualization, data mining, information design, graph drawing, computer graphics, cognition sciences, perception theory, and psychology (Carroll, 2003; Ebert, Gershon, & Veer, 2012; Zhang & Galletta, 2006). An overview of issues that are considered by HCI is depicted in figure 3.1.

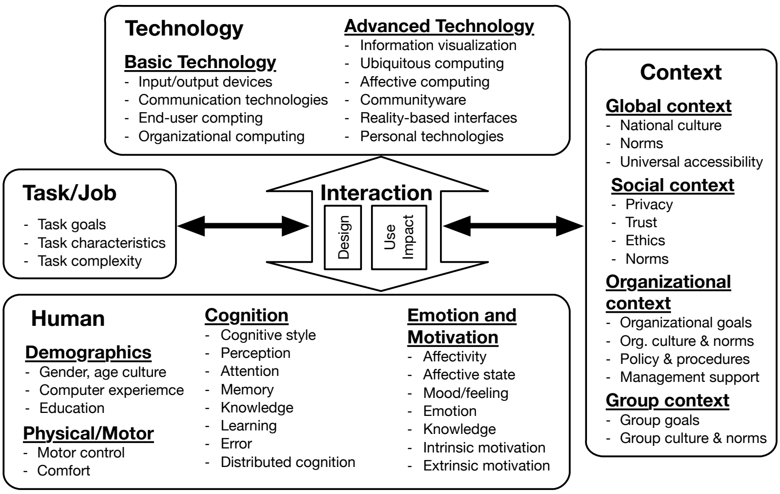

Figure 3.1. A broad overview of HCI issues. *Adapted from Zhang and Galletta (2006, p. 4).*

From the mid 1980s, the interest increased to study small-groups of individuals working on PCs, workstations, or minicomputers that were connected by networks. An additional focus was to study organizational use of technologies (Jacko, 2012). From that, the subfield of computer supported cooperative work (CSCW) emerged, which explores the effect introduction of technology can have on the organizational structure and how the way of work is affected within organizations (Zaphiris & Ang, 2009). The goal of CSCW and its applications are to supplement, and not to substitute, place-based work practices. Accordingly, CSCW imply a shift in methodology from focusing on the individual to a focus on a whole consisting of humans, computers, and other technologies that make it possible to work distributed and in cooperation.This move in unit of analysis can be described by Perry's statement (2003, p. 195):

> CSCW moves the study of HCI from a focus on the individual toward that of multiple, codependent users, and on the social organization of their work. It involves the analysis and development of tools and technologies to support the interactions of these co-workers. This necessitates a close examination of work and the context that such work is performed within. The role of context

in facilitating human activity has become a central feature of research within CSCW, as are the development of appropriate methods for workplace analysis.

Accordingly, the shift from the traditional study of individuals performing tasks with support from a computer to studying a whole, or a system, becomes apparent within the field of CSCW where the aim is to provide design of technology that supplement work practices, additional theoretical frameworks have been developed.

3.2 The PACT-framework

The core of the theoretical foundation used in this thesis is the PACT-framework explained by Benyon, P. Turner, and S. Turner (2005) and considers development of interactive systems. Furthermore, it is compliant with the definition of usability and its operationalized criteria (section 3.1). PACT stands for *People, Activities, Contexts,* and *Technologies* and the elements of the PACT-framework are described more in detail below. *Interactive system* is a term used to describe technologies that are concerned with information processing and consist of components, devices, products, and software systems. Interactive systems also deal with transmission, display, storage, and transformation of information to perceive and respond to actions (cf., section 1.1). The PACT-framework develops the principles and methods of HCI and is utilized to describe how people use technologies by undertaking activities in a certain context, and the way the elements change in relation to each other. When performing a PACT-analysis it is possible to address and categorize constraints that characterize a situation of interest. Outlined below are some important aspects of the elements described by Benyon (2010, p. 28-44).

People use technologies different and three aspects are considered more important. *Physical differences* where physical characteristics and variability in the five senses has a huge effect on how accessible, how usable and how enjoyable using a technology will be for people in different contexts. People also have *psychological differences* that may refer to spatial ability, memory, and ability to work under stress. In addition, language and cultural differences affect how people understand and interpret things. Also *social differences* affect how technology is utilized. For example, whether a particular design is aimed at satisfying the needs for a homogeneous or heterogeneous group of people.

Activities have many characteristics that designers need to consider. However, focus should be on *Temporal aspects* that encompass how regular or infrequent activities are, response times, and time pressure. An additional feature of activities is whether they can be carried out by a single individual or if they must be carried out with others. In the latter case, *cooperation* can be necessary where issues of awareness of others and communication and coordination becomes important.

Contexts are often useful to consider as surrounding an activity. At other times it can be considered as the features that glue some activities together into a coherent whole. Contexts are divided by Benyon (2010, p. 37) in three groups. *Physical environment* in which an activity take place. The *social context* where a supportive environment will provide help for the activity if people get into trouble. The social context also can affect interaction depending on privacy issues, if a person is alone or if the activity takes place with others.

Technologies, which are the last part of the PACT-framework. Four main components are focused on by Benyon (2010, p. 38-44). *Input*, which concern how people enter data and instructions into a system securely and safely. *Output*, which concern technologies for displaying content primarily based on the three perceptual abilities of vision, hearing and touch. *Communication* between people and between different kinds of devices is an important part of designing interactive systems. Finally, *content* which concerns the data in a system and the form it can take. It is also important that the content is accurate, relevant, appropriately presented, and up to date.

The PACT-framework is holding a human-centered view, which imply that it considers humans as; creative, compliant, attentive to change, resourceful, and able to make flexible decisions based on context (Benyon, 2010, p. 12). Accordingly, the PACT-framework develops principles and methods of HCI from what can be considered a bottom-up perspective. The objectives of the research in this thesis; however, also include a necessity for top-down creation and use of abstract scenarios to capture the main characteristics that exhibit desired properties of future C^2 situations and C^2 environments (section 1.2). A top-down and designer centered perspective is provided in Benyon and Macaulay (2002), which can be used to augment PACT scenarios with elements needed to realize PACT activities that need ICT support. These elements are *Functions, Interactions, Content* and *Services* (FICS), which delineate how an intended system should mediate the users' activities and form a desired description of the intended system. In terms of a PACT–FICS perspective, inquiries in this thesis are based on development of suitable scenarios in accordance with claims and assumptions outlined in section 1.2 and 2.1. For this purpose, a template including the PACT–FICS main characteristics was used as depicted in table 3.2.

Since the PACT-framework develops the principles and methods of HCI, it also provides the possibility to utilize additional theoretical frameworks that offer guidelines of thought and methods to undertake scientific inquiries. Two such frameworks are presented below that have been used for that purpose in this thesis.

Table 3.2. *A summarized template depicting development of conditions for inquiry according to the PACT–FICS framework.*

FICS scenario	A top-down scenario type describing an envisioned crisis situation that reflects overall claims and assumptions of future characteristics of command and control situations.	
PACT analysis		
People	The aim is to satisfy the needs for a group of decision-makers sufficiently trained to accomplish an assigned mission.	
Activities	**Temporal aspects**	Possible time pressure because of high or low tempo of own and others' activities. Is cooperation, coordination, and communication necessary to uphold or increase SA and accomplish the mission?
Context	**Complexity**	Is the mission characterized by solving tasks under high or low levels of complexity?
	Physical environment and social context	Laboratory environment where individuals and/or teams are tried under different conditions.
	Organizational context	Hierarchical Networked Self-synchronized
Technology	**Input**	Manual Automatized/Real-time Messaging • Text (e-mail) • Graphical • Combination thereof
	Output	Manual Automatized/Real-time Everything visible on user displays ("Gods view") Visualization of the situation limited depending on actual sensor reach
	Communication	Verbally allowed Verbally not allowed Fully connected Restricted Text only Graphically supported
	Content of data	Messaging • Text (e-mail) • Graphical • Combination thereof Real time Delayed

3.3 Sociotechnical systems theory

The development of sociotechnical systems (STS) theory can be derived from the work of von Bertalanffy (1968), his development of GST, and thus from the concept of open systems (Majchrzak & Borys, 2001). Accordingly, the ideas that later formed the theory of STS are not new and go back to the 1950s when British work sociologists introduced the term (Bansler, 1990). Early contributions to STS included approaches to design of jobs and work systems (e.g., see Emery & Marek, 1962; Emery & Trist, 1969; Trist & Bamforth, 1951). With inspiration from that work, Enid Mumford suggested to use the ideas of STS for computer system development (e.g., see Mumford, 1968, 1973, 1974; Mumford, Mercer, Mills, & Weir, 1972).

The currently most widespread use of STS theory reflects certain specific methods to design organisations that exhibit open systems properties and can thus cope better with environmental complexity (Walker, Stanton, Salmon, & Jenkins, 2008). To accomplish a task or objective, both the social and technical elements must work together as a unified whole forming an operating system that produce both physical products and social/psychological outcomes. Accordingly, the key issue is to design and distribute the work so that the two parts yield positive outcomes. In terms of STS theory, a successful distribution of tasks between man and technology is called *joint optimization* (Appelbaum, 1997). Unfortunately, it is common that the optimization is single sided, either by the "socio," or far more commonly the "technical," which tends to increase unpredictable and harmful relationships to a system's performance (Walker et al., 2008, p. 480). However, principles are provided to accomplish joint optimization in line with STS theory (Cherns, 1976).

Referring to section 1.2 and 1.3 above, this thesis can be widely summarized concerning different aspects of design criteria with properties that are assumed to improve effectivity, performance, and efficiency both for the system viewed as a whole and how it perform with a C^2 function provided with novel technology. However, from a STS perspective, also the C^2 function can be viewed as an open system in its own right. From this follows that the C^2 system both have to manage the "internal system," and capability to affect the external environment by using available means (cf., Emery & Trist, 1969). Managing the internal system can be regarded equivalent to controlling available subordinate subsystems; thus, its available assets. Such assets can, for example, be available human competence and technologies, which are appropriate combined to perform a given task or objective by joint optimization. Aside from providing means to achieve joint optimization, STS theory also is concerned with the system work and performance as a whole and in relation to its environment. From this follows that STS theory also involves management of boundaries of the system of interest as well as interdependencies among its parts. This observation was also made by Cooper and Foster (1971, p. 468) who put forward that both humans and machines have to complement each other to work effectively. Furthermore, Klein (2013, p. 2) stress that STS theory:

> [M]akes explicit the fact that the technology and the people in a work system are interdependent. Each affects the other. Technology affects the behaviour of people, and the behaviour of people affects the working of the technology.

From hitherto briefly outlining STS theory, it is possible to state that its unit of analysis mainly concerns a "system". However, the meanings of the term "system" also contain diversities, which can be illustrated by Rosen's (1986) observation:

> [T]he word "system" is almost never used by itself; it is generally accompanied by an adjective or other modifier[…] This usage suggests that, when confronted by a system of any kind, certain of its properties are subsumed under the adjective, and other properties are subsumed under the "system," while still others may depend essentially on both.

Hence, it is beneficial to provide and agree upon a definition on the meaning of "system" and its denotation in this thesis. The general meaning of the term "system" represents a set of some things and a relation among the things. This is however, a *common-sense* definition that can be formally expressed by the symbols **S**, *T*, and *R*. Klir writes (Klir, 1991, p. 5, emphasis in original): "**S**, *T*, *R* denote, respectively, a *system*, a *set of things* distinguished within **S**, and a *relation* (or, possibly, a set of relations) defined on *T*."

$$\mathbf{S} = (T, R)$$

The definition is simple in its form, but the symbols *T* and *R* have an extremely rich content. *T* represent a set of all possible things and *R* represent all relationships defined by *T*. Although the definition is primitive, Klir (1991) argue that it, paradoxically, both are its strength and its weakness. Since a common-sense definition like this is too general it becomes weak and of little pragmatic value. However, it is strong since it covers other and more specific system definitions. This most general system definition namely provides a criterion by which it is possible to determine whether any given object is a system or not. Viz., an object is a system if, and only if it can be described in a form that conforms to the expression above. For this thesis purpose the following, and more precise, definition of a 'system' is found applicable (INCOSE, 2012):

> [An] interacting combination of elements to accomplish a defined objective. These include hardware, software, firmware, people, information, techniques, facilities, services, and other support elements.

The definition admits that STS theory can be applied on both a system viewed as a whole or one of its subsystems currently of interest. Furthermore, it is possible to relate STS theory where technology and sociological issues have to be balanced to accomplish the objectives or goals prescribed. Accordingly, the challenge to combine two types of systems that are fundamentally different when instantiating STSs (Fischer & Herrmann, 2011):

- Technical systems that are produced and continuously adapted to provide a reliable, anticipatable relationship between user input and the system's output.
- Social systems that are the result of continuous evolution including emergent changes and behavior.

Although STS theory can be considered prescriptive regarding overall objectives when designing C^2 systems, it does not provide clear guidelines *how* to accomplish these objectives. A central problem of socio-technical design is the integration of technical functions with social structures and perspectives (Herrmann, 2009, p. 337). Despite this, STS theory can serve as basis to guide and accomplish design of suitable artifacts for C^2 work with support from other scientific fields that can provide methodology and methods satisfying these needs.

3.4 Distributed cognition

From the reasoning above, teams that are exercising C^2 work can be viewed as systems of distributed cognition (DCog) (Hutchins, 1995, 2001). DCog provides a theoretical framework for the analysis of data from sociotechnical systems within a problem-solving framework where the unit of analysis is a cognitive system composed of individuals and the artifacts they use (Kimani, Gabrielli, Catarci, & Dix, 2009; Perry, 2010). Accordingly, DCog is often considered to mean cognitive processes that are distributed across the members of a social group (Hutchins, 1995, 2001; Solomon, 1993). In addition, DCog is characterized by several individuals and/or teams working together to achieve some common goal, which often consist of multiple interacting subgoals. To achieve the common goal, the individuals and teams have to establish a common ground for understanding of the situation. This understanding, or knowledge, of the situation is formed by the interactions among individuals and by using shared artifacts where the knowledge is co-constructed, prominently by means of negotiation practices (Stahl, 2006, p. 183). Furthermore, often high levels of coordination and communication is required to achieve this, where support of different technologies have an important role. Accordingly, building an understanding and the knowledge of how far the common goal is achieved or a common assessment of a situation is not only a matter of an individual's mental representations, but is frequently distributed among the abilities of group members and the artifacts that they use (Hutchins, 1995).

However, as Stahl (2006, p. 197) put forward, cognition among cooperating individuals requires detailed analysis and understanding of collaboration to design activity systems or shared worlds around such systems. In addition, achieving group or team cognition is not automatically solved by offering certain functionality in a technical system. Accordingly, designing appropriate systems becomes a sociotechnical problem, which reconnects the framework of distributed cognition to sociotechnical systems theory.

3.5 Methodology

The research in this thesis starts from the ROLF 2010 vision and its proposed C^2 center, embodied by the SNDC C^2 laboratory. From a PACT-framework perspective, the design of the SNDC C^2 laboratory was aimed at satisfying the needs of a temporary team of decision-makers that were assigned to handle some type of military crisis situation. In the laboratory environment new technologies, not available on the market at the time, was implemented. New technologies often provide several new possibilities to make efficiency enhancements. Partly through the technology itself and partly by new working methods. In the ROLF 2010 vision, this was reflected in several assumptions based on how novel technologies could provide better prerequisites for exercising C^2. For example, that introduction of new technologies would change the way of working and thus becoming more efficient. The research in this thesis began with an analysis of made assumptions that sometimes did not appear to be reasonable, at least not always. Accordingly, there was an initial need to collect empirical data to gain understanding and experience from how C^2 work is conducted under conditions where assumed technological means are available. Moreover, arrangements were made to initially make it possible to observe what happens when C^2 is conducted from a setting like the SNDC C^2 laboratory. Thereafter, a tool was needed and developed to simulate "future" possibilities for exercising C^2. This was accomplished by development of the C^3Fire microworld. Finally, it was necessary to investigate and find various measuring points to evaluate whether some of the assumptions actually were true.

Hence, an initial observation study was conducted. However, qualitative studies often are too general to provide means of measurement and quantitative evaluation. Accordingly, the results from the initial study are used as basis for further experimental studies which also provide better possibilities to control the studied phenomena of interest. To evaluate the efficiency and effectiveness of assumed technological characteristics, working procedures, and organizational design, methods are used from experimental psychology and statistics. For each study reported in this thesis, specific issues of research and questions are investigated. For details, the reader is therefore referred to the original papers provided in the article part.

3.6 Summary

In this chapter, the theoretical basis and complementary scientific perspectives have been introduced. In addition, methodologies used have been presented. The core of the theoretical foundation for this thesis is the PACT-framework augmented with FICS for creation of suitable scenarios for inquiries of claims and assumptions put forward by the ROLF 2010-vision and the concept of NCW. In addition, complementary perspectives are used to support development of methods and measurements of performance and evaluation of efficiency according to usability criteria. These perspectives are represented by the scientific and theoretical frameworks of STS theory and DCog, which can be considered compatible with each other and with the PACT-framework. The methods used are both qualitative and quantitative. The initial and exploratory study is used to gain understanding and experience for the area of research. From this understanding, empirical studies based on methodology from experimental psychology are performed.

4. Information—an assumed enabler for better performance in command and control

There can no longer be a question about whether the brain models its environment: it must.

Conant and Ashby

To exercise military C^2 is basically a human activity that is carried out by a single or several participating individuals to accomplish some overall objective. As pointed out in the previous chapter, commanders' access to timely and purposeful information about the situation at hand often are crucial to accomplish an overall objective. The need for adequate information to create understanding of a C^2 situation and to be able to make sound decisions on appropriate action(s) is not new and put in writings already in the last half of the fifth century BC (Sun Zi, 2011, p. 91-94). A more contemporary argumentation is put forward by Holley (1988) who stress that effective command [and control] requires a continuous flow and communication of information up and down the organizational chain and recognize that information can be provided routinely as well as contributed by a local initiative. However, what is information to one person may not be to another. This situation leads to what may be considered as a problem with the term "information," which also can influence the interpretation of different concepts related to C^2. Therefore, what is interpreted as information is also related to various "schools of thoughts."

4.1 Reflections on "information"

The importance of addressing different and sometimes conflicting notion of "information" is reported in Knox (2007). While considering that "information" is something that can be communicated, there are at least seven scientific traditions of human communication that provide different perspectives of its meaning (Griffin, 2006). Since "information" is central and often is considered as a leverage and an enabler to accomplish the objectives in the NCW concept (section 2.1), agreements of its denotation may facilitate communications

among stakeholders. Accordingly, it seems necessary to put forward some aspects regarding the meaning of "information."
Not all notions of "information" and in addition its relation with data and knowledge will be considered here. A common perspective is, however, the hierarchical. Viz., that data are a prerequisite for information, which in turn often is considered as a prerequisite for creating knowledge and wisdom (e.g., see Lawson, 2010; Skyttner, 2005a).

4.1.1 The cybernetic/hierarchical view on information

One example of the cybernetical/herarchical reasoning is given in Checkland and Holwell (1998, p. 88-98). The authors' position begins from accepting the obvious in that there the set of facts about the world we live in can be regarded as infinite. Hence, "facts" are considered as the starting point for our mental processes. In addition, the term "fact" is considered equivalent with "data." However, from that we are not interested in all data that are available. We choose among data that are selected because they draw our attention or to create some new category. Such selected data are labeled *capta* (fr. Lat. *capere* to catch). Furthermore, as we enrich capta by putting it in a larger context and by attributing meaning to it information is created. This transformation can be both individual and collective, which, according to the authors, also corresponds to the everyday use of the term "information." In addition, as meaningful information itself can lead to larger structures of information, which is expected to have a greater longevity, the authors propose that the term "knowledge" is appropriate to use (figure 4.1).

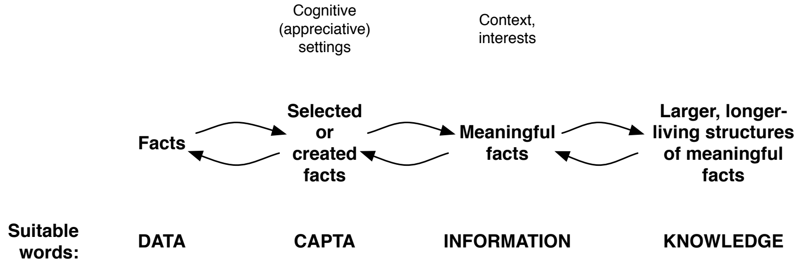

Figure 4.1. The links between data, capta, information, and knowledge *Adapted from Checkland and Holwell (1998).*

Checkland and Holwell's (1998) perspective on how to interpret the terms and the transformation from data to knowledge have several counterparts. However, there is an important difference since they introduce the term capta. This has particular bearing on what can be, cannot, and what is stored in information systems. Thus, an important observation made from their reasoning is that there is always a choice behind of why something is considered as "information." Furthermore, by analogy with their reasoning in relation to current use of computers and information technology, we should be talking about "capta machines" and "capta technology." However, this is far fetched since we are faced with an established terminology.

4.1.2 Information viewed as a process, as knowledge or as a thing

Buckland (1991) argue that it is desirable to develop an understanding of 'information' that is applicable for the various senses in which it is a need to talk about "information." Buckland (1991) distinguish three common definitions of "information" that represents approaches toward information; (1) as a process; (2) as imparted knowledge; and (3) denoted as a "thing" that is regarded as informative. From these uses, Buckland provide four aspects of how to interpret the term and provide a basis for classifying disparate information-related activities by considering the meaning of "information" in terms of; (1) entities and processes; and (2) abstract and concrete (figure 4.2).

	INTANGIBLE	TANGIBLE
ENTITY	**2.** Information-as-knowledge Knowledge	**3.** Information-as-thing Data, document
PROCESS	**1.** Information-as-process Becoming informed	**4.** Information processing Data processing

Figure 4.2. Four aspects of how to classify "information". *Adapted from Buckland (1991, p. 352).*

Where information is viewed as a process, someone is informed that the knowledge about something is changed. Thus, it is possible to talk about a transformation from one individual's cognitive state to another. Where information is viewed as knowledge, Buckland refer to what someone actually perceives during the information process. Here, a distinctive feature with information is that it is immaterial, abstract, and that it cannot be measured directly. Both cases imply that it is not possible to say with certainty what is information for one individual also is it for someone else. Thus, it is only possible to perform indirect measures to determine just how much information has affected an individual's total body of knowledge. Based on impressions, an individual will obtain and form the knowledge, faith, and beliefs by choice, or perception. These are personal, subjective, and conceptual, and to be able to communicate these it can be done by for example a signal, a text, or any other form of representation that all fall within the category of what Buckland advert to as "information-as-thing."

Buckland argue that "information-as-thing" is composed of subjective assessments and shows that it also is situated. Furthermore, what here is treated as information is dependent on both agreements and partly as results from consensus. From where a consensus is reached, judging what is considered as information, Buckland stress that the consensus is sometimes so strong that the status of objects becomes undisputed. However, since decisions on what should be regarded as information is based on a compounding of judgments, it is not surprising that disagreements may arise (Buckland, 1991, p. 357). In addition, "information-as-thing" is expressed and distributed by different forms of representations that have the following characteristics (Buckland, 1991, p. 358):

1. Every representation can be expected to be more or less incomplete in some regard[…] Something of the original is always lost. There is always some distortion, even if only through incompleteness.
2. Representations are made for convenience, which in this context tends to mean easier to store, to understand, and/or to search.
3. Because of the quest for convenience, representations are normally a shift from event or object to text, from one text to another text, or from objects and texts to data[…].
4. Additional details related to the object but not evident from it might be added to the the representation, either to inform or to misinform.
5. Representation can continue indefinitely. There can be representations of representations of representations.
6. For practical reasons representations are commonly (but not necessarily) briefer or smaller than whatever is being represented, concentrating on the features expected to be most significant. A summary, almost by definition, is an incomplete description.

The development of ICT has admitted, and probably will continue to provide new and improved possibilities, to create representations that can be widely distributed. However, as Buckland points out, the only information that can be dealt with directly by information systems cannot be other than "information-as-thing." To round out the different aspects of 'information' presented here, the technical-abstract use of the term often is practical. Equally often; however, it is not taken into account that for something to be characterized as information it must be assigned and contain meaning. Because it is not always obvious what different stakeholders mean by information, it is important that these different perspectives are clarified to avoid misunderstandings. Thus, the characteristics of representations above are particularly important to bear in mind when exercising computer supported C^2 work.

4.2 The assumption of shared information as a leverage for more effective C^2

One of the most central assumption of NCW to accomplish advantages to an adversary is access to efficient, and importantly commanders' access to shared and timely "information." By having access to timely information on all levels of command is assumed to provide, for example, improved SA, easier and more efficient targeting, information dominance over an adversary, and to implement organizational concepts that recognizes self-synchronization (cf., definition of NCW in section 2.1). From this, it is possible to derive additional assumptions that also are related to Boyd's thinking (section 2.5). By reconnecting to the characteristics and properties of a network-centric military system as described in section 2.1, such a system is in essence all related to availability of data (information) and their timeliness for purposive execution of C^2. Central in this line of thought it is implied that by providing a shared or a common operational picture will unify and homogenize commanders' understanding and thus their situation awareness (SA).

The concept of SA can be considered as a term given to the level of awareness that an individual has of a situation (Salmon et al., 2008). A commonly used definition of the SA concept, which has been and still is used extensively in various domains, is the one provided by Endsley (1988, 1995b):

> [T]he perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.

When defining the term Endsley refers only to the portion of a person's knowledge that pertains to the state of a dynamic environment. Hence, all knowledge a person possesses, for example established doctrine, rules, procedures, and checklists, do not fall under the concept of SA although it could be relevant and important for the decision-making process. Endsley argue that such knowledge sources are fairly static and therefore fall outside the boundaries of the term. Furthermore, Endsley recognize SA as a construct separate from decision-making and performance and writes (Endsley, 1995b, p. 36);

> Even the best-trained decision makers will make the wrong decisions if they have inaccurate or incomplete SA. Conversely, a person who has perfect SA may still make the wrong decision […] or show poor performance.

In the latter case she refers these phenomena to lack of training on proper procedures, poor tactics, and for some reason the decision-maker could have an ability to fulfill the necessary actions. According to Endsley's definition, SA consists of three hierarchical phases;

• Level 1 SA – Perception of the elements in the environment
• Level 2 SA – Comprehension of the current situation
• Level 3 SA – Projection of future status

The first level relates to SA gained by perception of the status, attributes and dynamics of relevant elements in the environment. The second level of SA is reached through an achievement of understanding and the significance of the perceived elements on level 1 in relation to pertinent goals. Finally, the third level is reached when an individual have the ability to project future actions of the elements in the environment. In addition, Endsley argue that this third level is achieved through knowledge of the status and dynamics of the elements and comprehension of the situation with predictions about action and environmental changes in the very near future (figure 4.3).

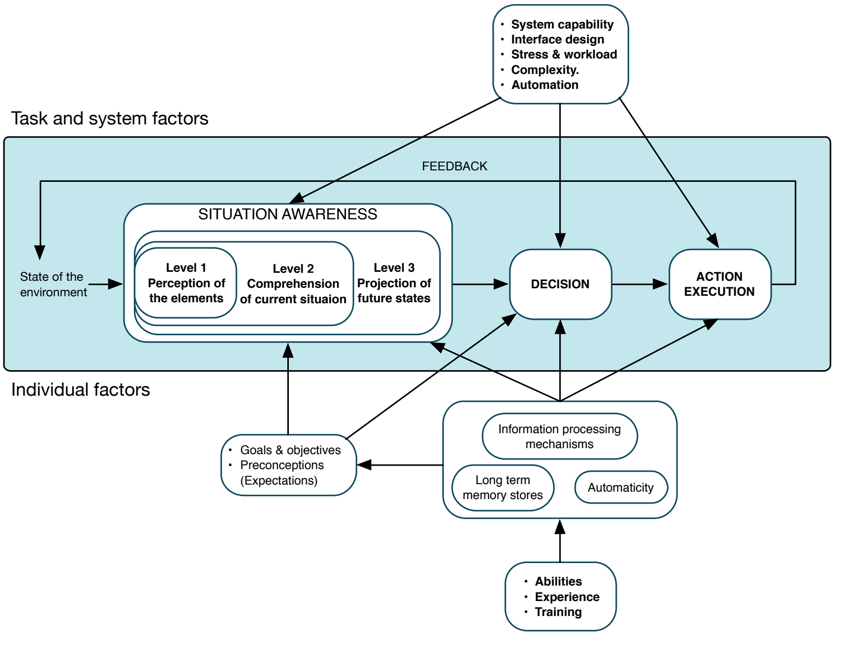

Figure 4.3. The three-level model of situation awareness (SA). *Adapted from Endsley (1995).*

In Endsley's (1988, 1995b) definition of SA, the focus is on the individual as a passive information receptor that can be understood in terms of elementary or hierarchically ordered cognitive processes. Other definitions of SA have been presented; however, despite several flaws are pointed out with Endsley's three level model and that it has been subject to criticism, other definitions and models have not gained the same impact (e.g., see Dominguez, 1994; Salmon et al., 2008). For example, Salmon et al. (2008, p. 305) point out that Endsley distinguishes between the product of SA and the processes that are used to achieve it and suggests that the two are separate. Moreover, they make the observation that Endsley's three level model is ostensibly a linear feedback model of SA and so ignores the notion that SA can be as much a feed forward phenomena as a feedback one. Also, Artman and Garbis (1998) put forward criticism to Endsley (1995b) and argue that:

> Endsley is treating the phenomenon [of SA] in quite traditional cognitive science models with the general focus on attention, perception and memory. SA becomes another box in the individual's mental machinery[…]

Artman and Garbis (1998) continue and state that the predominant perspective treating the phenomenon of SA is individualistic and mentalistic, which imply that a human actor becomes a passive recipient of information, or an information-processing unit that encodes and retrieves information from memory. These arguments are similar to Bedny and Meister (1999) who point out that the model of Endsley (1995b) is not logically consistent and writes (p. 65): "her model of SA is treated simply as another box in a flow diagram of the human information processing system. However, SA, decision making, and performance of action as stages of information processing suggest the involvement of various psychic processes, without which none of these stages can function."

In contrast, an ecological perspective of SA is provided by Smith and Hancock (1995) and defined as adaptive, externally-directed consciousness that has as its products knowledge about a dynamic task environment and directed action within that environment. By this definition, Smith and Hancock (1995, p. 142) argue that SA is more than "a snapshot of the agent's current mental model." Furthermore, that SA also guides the process of modifying knowledge by constructing a representation of current events as well as events that might happen or can be anticipated. This view is comparable and compatible with Persson and Rigas (2007) who stress that SA should not be understood in terms of elementary or hierarchically ordered cognitive processes, but rather complex mental activities that demand overlapping sets of cognitive processes.

Aside from individual SA, Endsley (1995b, pp. 38) suggest that her perspective also is applicable on teams, which lead to shared SA. Shared SA is defined as (Endsley, 1995b, p. 39): "the degree to which team members possess the same SA on shared SA requirements." From this definition, Salas, Prince, Baker, and Shrestha (1995) conclude that the information requirements relevant to each individual team member and the overlap of these requirements among the team members are both essential elements of SA in a team. Accordingly, from the perspective provided by Endsley (1995b, 2003), shared SA can be viewed as a function of each team member's SA. Based on these terms; however, measuring shared SA has proven difficult (e.g., see Nofi, 2000; Salmon et al., 2008). Nevertheless, both individual and particularly shared SA is considered important in the NCW concept. In the latter case it also is considered characteristic on the force-level (cf., table 2.2).

Again, Artman and Garbis (1998) suggest that a perspective of DCog should be taken, which also is incentivized by that most C^2 centers consist of one or more teams where each individual has some specific responsibility and role to control dynamic systems. The DCog perspective provided by Artman and Garbis (1998) also implies that a sociotechnical, and thus a system oriented view can be applied to the concept of SA. This has recently been further elaborated and developed to a nascent theory of distributed situation awareness (DSA) (e.g., see Salmon et al., 2008, 2010; Sorensen & Stanton, 2013; Stanton, 2013; Stanton, Salmon, Walker, & Jenkins, 2010, 2006).

4.3 Summary

From the many claims and assumptions made within the concept of NCW, one of the most important is to accomplish availability of critical information, and to dispose over means that enables distribution and communication of information. This seems appropriate when using an everyday definition of information. However, putting this definition of information aside in account for how 'information' is scientifically denoted implies that it is created by data or signals that are interpreted by an individual. Besides that these data or signals have to be interpreted, they also have to be assigned meaning to become information. Hence, if this does not happen there is an obvious risk for data and signals to pass unnoticed.

Considering the meaning of "information" in the context of NCW becomes somewhat ambiguous. Accordingly, to facilitate communication, to avoid misinterpretations and/or unreasonable expectations among stakeholders, it is often beneficial to define a term such as "information". For example, during different stages of theoretical, concept or system development. The importance of "information" in NCW is also manifested as a leverage in the concepts of individual and shared SA. Furthermore, the SA concept can be regarded as a prerequisite for information superiority, speed of command, and as an enabler of organizational adaption to a current situation, etc. However, the extensive use of Endsley's definition of SA has had implications for how it can or should be measured, both when it comes to measuring performance of individuals or teams (Nofi, 2000, p. 47). A promising approach seems to be a continued development of DSA and to adopt a sociotechnical system perspective for development of SA measurements.

5. Summary of papers

Four papers are included in this thesis. The empirical study reported in the first paper are based on an exploratory study. The second paper summarizes experiences from using microworlds in research on team decision-making. The final two papers are based on general methodological approaches from experimental psychology and statistics.

5.1 Paper I: Old Practices - New Technology: Observation of how established practices meet new technology

This first paper describes an observational study of the first exercise held at the prototypical device in the SNDC C^2 laboratory. The study start with the question of how new technology is introduced and used within a socially homogeneous community. This question, however, is less coupled to what technology enables than to what the social context allows. The background for this is twofold. First it is related to the assumptions made in the ROLF 2010 research project and a prototype developed within the closely related AQUA project. Second it has a relation to an evaluation that representatives from Swedish National Defence Research Establishment (FOA) performed during this exercise.

The ROLF 2010 project's purpose was to develop a general vision about future command and control on the operational level for the Swedish Armed Forces (SweAF). The vision describes how command and control units of Sweden's national defense and rescue services may appear within 10-15 years time. In the original ROLF 2010-vision, a C^2 unit is equipped with three identical modules that are manned with forty staff members. One module is responsible for implementation and one module is responsible for planning and surveillance of the environment. The third module is held in reserve to be used for different purposes. The vision also conforms with a widespread opinion that success in future C^2 will be dependent on the ability to quickly understand and control a dynamic situation. This is assumed to be achieved by the capability of dominating the information environment or to be ahead of the actual situation. Being able to do that creates a need for support from future technological development, which will provide e.g., novel and high capacity decision support systems (DSS) and new planning tools. From here, the

ROLF 2010 project generated an idea of a device that can provide customized presentations of a situation, support for decision-making and distribution of decisions. The device is called the *Visionarium* and includes a *Visioscope* (figure 5.1).

Figure 5.1. An illustration of the ROLF 2010 idea of a device that can provide customized presentations of a situation, support for decision-making and distribution of decisions. *Illustrated with permission by Martin Ek, FOA tidningen.*

The basic principles that are used for the design of the C^2 post in the ROLF 2010 project is mainly founded on three metaphors, which are presumed to facilitate C^2 work (Sundin & Friman, 1998, p. 67-68):

1. A campfire metaphor, which is inspired by how people in all times have gathered around a campfire to discuss problems or to enjoy themselves.
2. A look-out metaphor, which is represented by large vertical displays. These displays are designed to provide opportunities to view actual conditions or capture real-time information from the field.
3. The look-in metaphor, which is represented by the horizontal screen of the Visioscope. This screen is used as a replacement of the traditional field map. It also provides means to present additional information such as different types of diagrams, resource diagrams, different flows, etc. These presentations are supposed to be made in combination or alone depending on what is most suitable at the moment.

The work of implementing and developing this idea was managed in a separate project called AQUA. The AQUA project's purpose was to create a research platform, which was supposed to enable that several research questions raised in the ROLF 2010 project could be investigated. The research platform was not as sophisticated as expressed in the ROLF 2010-vision. With some respects; however, it provided possibilities to mimic some of the vision's functionality by manually updating a current situation with new data on the displays (figure 5.2). Such updates were carried out from an external training organization located outside the SNDC C^2 laboratory.

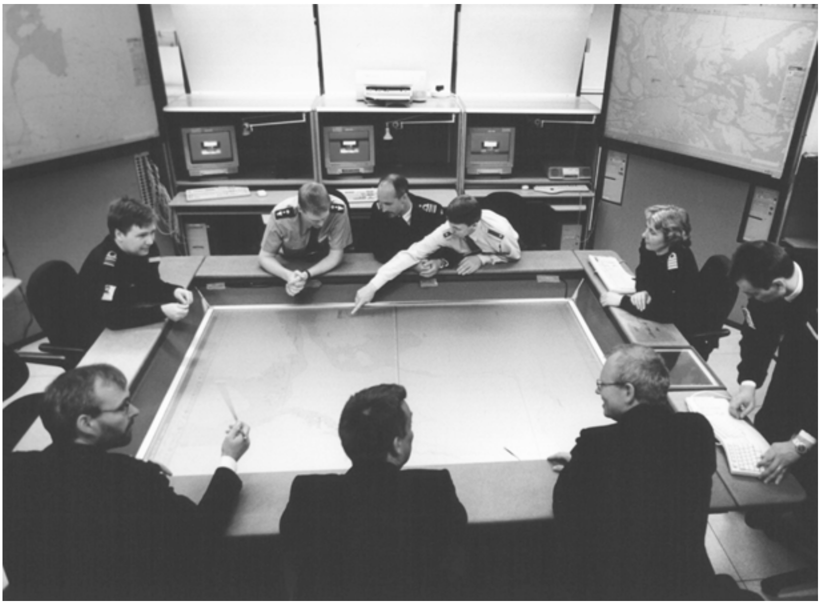

Figure 5.2. A live picture from the SNDC C^2 laboratory during the planning for the training session, spring 1999. *Photo with permission by Martin Nauclér.*

In spring 1999, SNDC organized the annual and recurrent training session for officers at the program for advanced command studies. For three days, the SNDC C^2 laboratory was used where a team of officers trained to control a crisis involving political and military aggression. The training session was observed by several parties. Lessons ascertained from these observations were that the interaction between the team members was severely regulated and distant.

The training session was also observed and evaluated by representatives from the independent agency FOA. Their emphasis was on how computers were utilized. One of their main critical points was that the team members did not have the adequate knowledge of how to use the technology. Their suggestion was thus to give the officers more training in handling the technology.

Predictions

From assumptions made in the ROLF 2010-vision, it is hypothesized that the participants' seating in combination with their use of collective technology will promote cooperation and creative discussions. Moreover, collective technologies are hypothesized to promote synergy effects between the participants' individual competence and the different functions they represent. In addition, collective areas for presentation are hypothesized to be used for creating a common view of the situation, which will be used for effective decision-making. If these hypothesizes are affirmative, then the corresponding assumptions in the ROLF 2010-vision are true.

5.1.1 The empirical study

The study presented in this paper was based on the FOA evaluation together with experiences from observations of how the team worked. The purpose of the study was twofold. First, to gain understanding if there were other reasons than inadequate individual knowledge why technology was not used as expected. Second, to understand why the creative discussions did not happen as presumed in the ROLF 2010-vision. With this understanding, the aim was to provide guidance of how to develop practices or at least to avoid what not should be done.

The whole three-day session was recorded on audio-video tape. The analysis of the audio-video recordings was focused on meetings where all team members gathered to share information and specifically on team interaction. Such events include about eight hours of the total amount of audio-video data collected.

The authors' observations were organized by initially studying the material individually from questions of general interest: (1) how the team used the technology; (2) in what way the team interacted; and (3) how the team used each others' information.

While individually studying the recordings, interpretations of the processes in the team were written down. Thereafter these interpretations were shared and discussed while observing the videos again. Where interpretations of a situation differed, an explanation was given why and how the interpretation was made and what it was based on. Finally, interactions were clustered in different categories whereafter the material was analyzed.

The team members gathered and organized each other typically in two forms of meetings to share information with each other. First, in a form of meeting that was categorized as *collective information sharing sessions*. During such meetings, all team members gathered to collectively report individual aspects of how the current situation could be assessed. Second, team members could start to interact and engage in dialog and more directly discuss problems inbetween the collective information sharing sessions. Those meetings were categorized as *sub-team interaction*. Beside these two forms of meetings, the team members were working individually with task assignments.

5.1.2 Results and conclusion

The results from the analysis of the observations can roughly be divided into the following main areas of interaction and communication patterns; (1) social; (2) use of common technology; and (3) use of personal technology. While summarizing some of the more interesting observations, initial reflections was made from one of the wished for effects in the ROLF 2010-vision.

One of the more important assumptions in the vision is the seating in combination with technology will encourage creative discussions. Furthermore, these discussions are supposed to break down formal rank. Thus, whenever there is an opportunity to contribute to the discussion a team member is supposed to and should feel encouraged to take the floor. This was, however, not what happened.

The way meetings were conducted did not correspond to the presumed behavior in the ROLF 2010-vision. Instead, during collective information sharing sessions the team members showed a traditional pattern of behavior. At the beginning of each meeting the commander established the agenda. Obviously, the commander distributed the order of speaking and the centrality of the commander was confirmed. Questions were rarely, if ever, asked when team members were given the floor to share information. Nor was the information or statements impugned by the other participants. Furthermore, common situation awareness was seldom discussed and a common view of the situation was never articulated. The team members' behavior during these sessions was thus distinguished as passive. In addition, it might contribute to complications when deciding on suitable or possible actions.

Considering sub-team interaction, these meetings were more *ad hoc* in their nature. Sub-team interactions took place between the collective information sharing sessions. Depending of the situation, those team members involved gather to more directly discuss and handle emergent problems. Apparently, this form of interaction was more vivid and dynamic than meetings where all members of the team were present. However, although sub-team discussions may be an efficient way to handle problems and assignments, there also are risks involved with this type of activity. For example, there are risks that earlier and collectively agreed upon actions to be taken are re-interpreted, which can lead to contra-productive actions viewed from a holistic perspective.

In this paper technology use is categorized as co-operative and personal. From the observations made, this sharp distinction between collective and individual work seems applicable. Considering co-operative technology, it generally is not used as frequently as expected and during collective information sharing sessions the vertical displays were not used at all. The last day of the training session, however, the team members developed individual and simplified representations of the situation. These representations were made collective during the information sharing sessions. These simplified representations of the situation were presented with use of the Visioscope. Although the representations provide an incitement to increase the discussion about the assessment of a situation, such discussions did not take place in a degree that was wished for. Accordingly, one conclusion is that the co-operative resources at hand did not directly correspond to the team members' needs to promote creative discussions.

The use of personal technology distinguishes itself from other technology use. Immediately after the information sharing sessions ended the team members turned to their individual work stations and worked quite intensely. From knowing available personal applications and from analyzing team agendas with the reporting character of the information sharing meetings, conclusions could be made that interaction and information exchange were more intense and frequent than the interaction with the team members.

The general conclusion from this study was that neither technology, nor the team members' seating turned out as expected in the ROLF 2010-vision. Instead, the result can be viewed as a clash between old practices and what new technology affords where the team members seem to be more coupled to their subordinate units than to the C^2 team.

Finally, it is possible to make some remarks that not are addressed in the paper. First, the study shows no effects of the work practices used. Since this was the first training session in the SNDC C^2 laboratory and only one team was observed; it follows that no comparison was made with a control group. Accordingly, it is not possible to determine what actually was accomplished. Second, the actual communication and communication patterns from personal work stations were not analyzed. The team members' access to crucial information for a complete situation assessment could have been widely distributed. Thus, it is not possible in this study to make conclusions about the team's common view of the situation. Third, the effect of more training before the exercise is and cannot be explicitly addressed. The reason of this is again resulting from the lack of a control group or other means of comparison.

5.2 Paper II: C3Fire in command and control research

The aim of the paper was to present experiences of how microworlds can be used to provide possibilities to create controlled settings and to use monitoring tools to study humans in command and control situations. The experiences presented are based on earlier observations in Artman and Persson (2000) and results from a previous experiment that was conducted within the framework represented by the ROLF 2010-vision (Johansson & Granlund, 2001; Persson & Johansson, 2001).

Studies of how humans, like commanders and teams, make decisions in situations that are characterized by time-pressure and uncertainties are most often of practical interest. This is sometimes in contrast to research within traditional theoretical frameworks where the focus instead is on theory and not practice. In this paper, a rather practical approach is suggested that is practical informed and based upon field observations and from different theoretical perspectives. In addition, visionary studies may imply difficulties and complicate the possibilities to test different assumptions of the future. An example of one such complicating factor is that visions may require technology that not is available today. Hence, also problems of this kind must be managed to meet such conditions and to be able to make relevant studies. Consequently, we propose, evaluate, and discuss a methodology that makes it possible to introduce real-world practice to microworld studies and where experiences of microworld studies can be transferred to actual practice.

Predictions

Based on assumptions in the ROLF 2010-vision and the NCW concept, it is hypothesized that participants performing a C^2 task under a condition where shared real-time representations of a situation is presented will perform better than under a condition where the representations are manually updated. Furthermore, from the experiences of study I, it is hypothesized that the C^3Fire microworld can provide some of the technological characteristics envisioned for future C^2 environments. In addition, it is hypothesized that participants performing a task provided by the C^3Fire environment will show an equivalent pattern of behavior as in a task environment provided by a traditional C^2 exercise. If the first hypothesis is affirmative, then the assumption that a C^2-team with access to real-time updates of units (elements) performing tasks under a dynamic evolving situation will perform better than under the condition where the development of a dynamic situation is manually updated. If the second and third hypotheses are affirmative, then the C^3Fire microworld will prove that it provides task environmental characteristics equivalent to traditional C^2 exercises.

5.2.1 The empirical study

The purpose of the experiment reported in this paper was to examine assumptions concerning digitally updated shared representations for future command centers. On one hand, the literature suggest that it is possible to gain an "information advantage" in critical situations by presenting aggregated data in near real- time to decision makers (e.g., see Alberts et al., 2001; Alberts et al., 2000; Potts, 2003). However, findings from command and control research do not support this claim to the extent expected (Omodei, Wearing, & McLennan, 2000). Thus, the question raised if the benefit of presenting data and information by shared representations actually is as suggested.

Based on this question, a study was performed using the C^3Fire microworld (figure 5.3). C^3Fire is a is a distributed command, control, and communication simulation environment for making studies of individual and group decision-making in a context of simulated forest fire. The purpose of using microworlds is to present a problem, yet recognizable, to the participants that is complex, possible to use and to handle. The level of complexity, however, must be so high that the participants are experiencing a dynamic situation and uncertainty. Because C^3Fire has enough level of abstraction examinations of complex issues become manageable for researchers to collect different data and to analyze. For participants C^3Fire provide a level of fidelity that is high enough to be acceptable.

One of the advantages with C^3Fire is that it provides extensive support for a training manager, or an experimenter, to configure the simulated environment. For example, how much information about the surroundings that should be presented to the participants. C^3Fire also provide possibilities to control to what extent the participants should be able to communicate with each other depending of their role or position (Granlund, Johansson, & Persson, 2001). In addition, all events that occur during a session are captured in log files that can be quantitatively analyzed.

In the experiment, a combined method was used where both quantitative and qualitative data were collected and analyzed. The experimental design was a comparative study where two conditions were examined. (1) *Direct updating* – where the participants representing rescue units "on the field" could input data directly on a shared representation. This condition was called the "map condition" and was compared to; (2) *Manual updating* – where the commanding staff in the ROLF 2010 environment had to update a common and shared representation by themselves. These updates were made based on e-mails that was sent from "the field". The latter condition was the "text condition", which has an ecological similarity to the old fashion way of working with paper maps. These two conditions were compared in a series of trials.

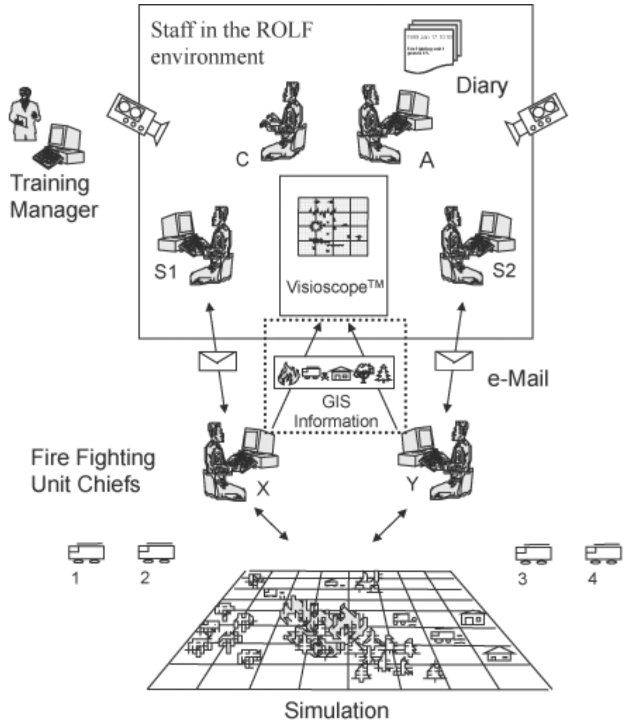

Figure 5.3. The C^3Fire microworld. When the participants extinguish a simulated fire, they must cooperate by communicating through available channels. C^3Fire is configured, controlled and monitored by the training manager (experimenter) with the support of script files.

5.2.2 Results and conclusion

From the results of this paper, a general conclusion could be made that the C^3Fire microworld was appropriate for making experimental testing of new command and control concepts. This regardless that results from the analysis of quantitative data, which showed no significant statistical differences in performance between the two conditions. Thus, it shown possible using microworlds like C^3Fire to simulate and investigate visionary and technological properties for a future C^2 setting. C^3Fire admitted configuration of both a "traditional" and a future or envisioned C^2 environment in a controlled and traceable manner. Further, analysis of the audio-/video recordings in combination with live observations also provided some interesting results for treating the main issue of this paper. One of these results is that not all data of interest under command and control studies can be captured or interpreted by quantitative data alone. This can be reflected by the observation where participants created dynamic problems and increased complexity by themselves, which not were generated by the simulation. Thus, a conclusion is made where (Johansson, Persson, Granlund, & Mattsson, 2003, p. 195):

“Simply involving a large number of persons under stress seems to reflect more real-world problems than the fidelity of the simulation.” Under the discussion in this paper also other aspects are put forward, which emphasize the use of the C^3Fire environment as a mean for reaching better understanding of C^2 work. For example, the high user acceptance of the participants with their quick adopted analogies to their own profession. The combination with qualitative observations to understand effects of different processes and work procedures, together with quantitative measures of performance, is said to indicate that the C^3Fire environment provides valuable insights of team cooperation in dynamic environments. However, these statements are not treated systematically or brought into evidence. Instead, they are brought up as new observations.

Some additional remarks can be made regarding the results presented in this second paper. If the assumptions in the ROLF 2010-vision would hold, a significant difference would have been in favor for the “map condition.” In the paper this is not discussed, but one possible explanation could be that the participants were all military personnel and that their understanding from the “text condition” was more similar to their ordinary command and control working situations. Another confounding variable, also not reported in the paper, could have been that the fire-fighting unit chiefs had to update the shared map manually under the “map condition” and simultaneously being occupied fighting fires. Hence, the updates could have been too inaccurate to reduce uncertainty among the participants performing their tasks in the ROLF 2010 environment.

5.3 Paper III: A measure of situation apprehension, outcome prediction and performance in one microworld

When working in a command center, it is important to create and uphold a good understanding of the situation and its development. In a military context, geographical maps with standardized symbols have traditionally been used to visualize and represent this understanding. To create as accurate representations as possible, collection of data from different sources is required. One important contribution to this is different reports on the situation; e.g., subordinate commanders' apprehension and assessed development of the situation within a certain time. In addition, the emergence and development of new technological means to obtain and to present data; e.g., computerized geographical information system (GIS), has given rise to new presumptions how such means can improve this capability as well as facilitate decision making. This leads to the focus of this paper where the aim was to to investigate how a dynamic situation is apprehended through a GIS, how accurate predictions can be made of an evolving situation, and how these two abilities are related to observed performance.

The need to create and uphold a good understanding of the situation has also found its expression in the literature by the concepts of sensemaking and SA. The most known reference of sensemaking is probably the effort proposed by Weick (1995, 2001) to explain collective action in organizations. When applied in the field of command and control (C^2) studies, the concept of sensemaking can be viewed as a descriptive process related to decision-making where; for example, awareness, understanding, and made decisions can be regarded as products from sensemaking (NATO, 2007). Consequently, it is possible to consider SA as a subset of the cognitive processes involved in the sensemaking process. The integrated definition of the SA concept suggested by Endsley (1995a, 1995b) has had a major imprint for research within the fields of human factors and decision-making. Endsley (1995b, p. 36) define SA as a product from a three stage bottom-up process where each level constitutes a precondition for the next. The levels comprise of: "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."

To validate and measure SA has, however, been shown to be impaired by difficulties (e.g., see Nofi, 2000; Salmon, Stanton, Walker, & Green, 2006), which led to our doubts whether it will ever be possible to measure Endsley's three stages in isolation. Also more recent findings suggest that the difficulties are a persistent problem (e.g., see Natter, Ockerman, & Baumgart, 2010; Salmon et al., 2008, 2010; Wickens, 2008). The authors' belief of the paper summarized here is that; at least some mental processes of those involved in understanding are top-down; measurement problems not only are technically related, but are dependent of mental activities that cannot be described in terms of the levels suggested by Endsley (1995b, p. 36). Hence, an alternative to the concepts of sensemaking and SA is proposed; (1) *situation apprehension*, which refers to the ability to exceed what is immediately given to perception; and (2) *outcome prediction*, which is a complex ability that requires not only to understand the development of a situation (prediction ability) but also to have possibilities to control or influence it.

Predictions

Assumptions made in the ROLF 2010-vision and in the NCW concept suggest that means of new technology for visualization of a current situation will increase the performance of decision-making. In addition, assumptions are made that real-time visualization of a current situation will facilitate the anticipation of its development. The suggested method for measurement of situation apprehension and outcome prediction is hypothesized to provide an alternative to the prevailing attempts to measure situation awareness (SA). In addition, the suggested method is hypothesized to provide results that can be compared with task performance. If the hypotheses are affirmative, the suggested method can be used as an alternative to current approaches to measure the effects of how a dynamic situation is understood and how that understanding might affect performance of C^2.

5.3.1 The empirical study

The study suggests and investigate a method to measure situation apprehension and outcome prediction psychometrically. To evaluate our measuring method we studied the relationships between apprehension, prediction, and performance in a dynamic situation created with the C^3Fire microworld. One of the main reasons that we used the C^3Fire microworld is that of its many configuration possibilities; e.g., to control; how much information about the surroundings that should be presented to the participants; the initial state of the simulation; how a scenario start, pause and finish, etc. (cf., the brief description of C^3Fire in section 5.3.1).

The evaluation was designed as a correlation study. The participants completed 12 scenarios in the C^3Fire microworld. The first eight scenarios were carried out so that the participants would receive basic skills with C^3Fire. The final four scenarios were used to collect data for the evaluation of our suggested method. During the last four scenarios, the C^3Fire microworld simulation was paused when the participants were asked to complete a form with a Logitech io™ pen where they should: 1) give their apprehension of the current situation; and 2) make a prediction of the result after finishing the session. The results from these forms were used to calculate the participants' scores of situation apprehension (figure 5.4) and prediction ability (figure 5.5). We compared these scores with the participants' performance in C^3Fire.

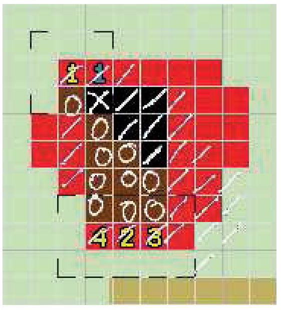

Figure 5.4. An example of how a participant apprehended and assessed a current situation during a pause. The white symbols derive from the overlay that was captured and generated with the Logitech io™ digital pen.

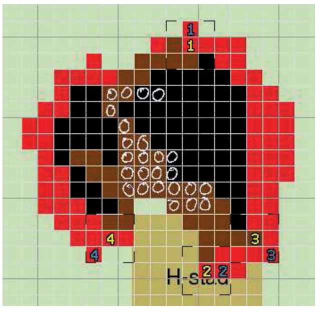

Figure 5.5. An example where a participant have made predictions of which cells he/she will have closed out when the session is ended.

5.3.2 Results and conclusion

The results showed that the reliability of the performance scores in the C^{3}Fire microworld was high. This was, however, expected from earlier experiences with C^{3}Fire in experimental settings. To measure the participants' situation apprehension and prediction ability, we based our calculations on signal detection theory (SDT) rates. Since the participants could view the map during the pause, only hits (a participant have made a correct response) and false alarms (a participant has given a response although it was not correct) were calculated. From the results of the SDT rates, participants with higher hit-rates tended to perform more successfully in C^{3}Fire. Accordingly, the correlation where participants made many false alarms tended to perform worse in C^{3}Fire. Although the number of participants (42 persons) can be considered as small, the reliability of the situation apprehension and prediction ability scores was statistically satisfactory. Thus, the measurement method constructed for the concepts of situation apprehension and outcome prediction were psychometrically acceptable. From our point of view, these concepts refer to rather complex mental activities that demand overlapping sets of elementary cognitive processes, which also are involved in decision making. Furthermore, our main conclusion of this study is that the concepts of situation apprehension and outcome prediction constitute a more promising alternative than current approaches in C^2 research to understand the concept of sensemaking or the concept of SA as suggested by Endsley.

5.4 Paper IV: Complexity: the dark side of network-centric warfare

This fourth paper is based on prior research within the field of distributed decision making (DDM) and military theoretical suggestions, which imply that a networked command and control (C^2) architecture can provide significantly more effective C^2 than those based on traditional C^2 architectures. Considering the main problems of exercising C^2 in military settings they also require the ability to handle different levels of complexity. Traditionally, this has been achieved by so called *mission command* or *Auftragstaktik* as it was implemented by the German Armed Forces during the nineteenth century. By mission command, delegation of responsibility to lower levels of command admitted a higher tempo of operations and a higher probability of success. From this follows that different levels of complexity also can become manageable within the areas of responsibility assigned to commanders on different levels. However, one of the disadvantages of mission command is the persistent problem of information delays.

Development of information and communication technology (ICT) has provided new means for mediation of data and information. In turn, new ideas and theories have given support for development of new C^2 architectures as those expressed within the concept of network-centric warfare (NCW). Based on that concept, some military theorists have suggested that networked C^2 architectures that provide increased connectivity between organizational assets will reduce information delays, increase the speed of command, and the tempo of future operations. Furthermore, the concept of NCW is assumed to increase shared awareness and thus contribute to better understanding of complex contexts and potentially increase effectiveness throughout the organization (Alberts et al., 2001; Alberts et al., 2000; Alberts & Hayes, 2007; Arquilla & Ronfeldt, 2000; Cebrowski & Garstka, 1998; Potts, 2003). The NCW concept; however, also open possibilities for central levels of command to take over tasks currently carried out on local levels. Thus, centralistic concepts for near real-time C^2 can be used in a way that has been impossible since implementation of mission command became a necessity. Still, the amount of information can be too large to handle on central levels of command. Accordingly, such circumstances might imply a need for a more decentralized form of organizational C^2 architecture to utilize networks for communication, distribution of work, delegation of responsibilities and to solve coordination needs. In this article, it is observed that the NCW concept thus seems to open possibilities for use of C^2 concepts that stretch from centralistic to decentralistic and that it could support extreme approaches in either direction. Under these circumstances, the introduction and pervasiveness of novel technologies, and changed conditions to exercise command and control might contribute to increased complexity that commanders must handle.

From a reasoning of complexity and its interdependence with requisite variety (see Ashby, 1956; Conant & Ashby, 1970), a working definition for the complexity exposed to a decision-maker under the experiment is provided. Hence, complexity in this article is viewed as:

> the sum of the variety created by the number of units controlled; their status; the relations between these units and their interactions; and any combination thereof that form a C^2 situation under which decision-makers have limited time to make decisions to act.

By adopting this view follows that complexity is defined by the number of units that a decision-maker must control per time unit and that complexity can be increased either by increasing the number of controlled units, tempo, or both. This view also complies with the proxy of complexity provided in section 1.2.

Predictions

Claims and assumptions made in the ROLF 2010-vision and in the concept of NCW suggest that technology will provide new and networked C^2 architectures that are more resilient to complexity than the traditional ones. In addition, networked C^2 architectures are assumed to result in more effective exertion of C^2. From these claims and assumptions it is hypothesized that networked C^2 architectures will perform better in comparison with a traditional C^2 architecture, both regarding performance and resilience to complexity. If the hypotheses are affirmative, they will result in statistically significant differences in performance between traditional and networked C^2 architectures.

5.4.1 The empirical study

The aim of the experiment in this article was to examine team performance under different conditions of C^2 architecture, their properties and their resilience to complexity as suggested in the NCW concept. Three conditions of C^2 architecture were tested in this experiment:

1. *Directive command* – this condition was a hierarchical C^2 architecture and conceptually the same as the hierarchical condition in earlier DDM studies. However, in contrast to these studies the commander's *only* task was to direct the subordinate team members in detail. Because only vertical communication was possible, all communication had to go through the commander. Furthermore, under this condition only the commander had access to the total view composed by what the individual team members saw locally.

2. *Command by negation* – was a decentralized and networked C^2 architecture where the commander had an *advisory* role. Moreover, the commander could by graphical means negate team members' decisions that he/she found inappropriate. All participants could communicate with each other and everybody had access to each other's local information.
3. *Control condition* – this was a C^2 architecture without any commander where none of the team members had access to the other team members' local information. Nor could the participants communicate with each other.

The C^3Fire microworld was used for the experiment to investigate the C^2 architectures' resilience to complexity. Based on experiences from earlier pilot studies new graphical symbols was developed and implemented in C^3Fire. This was carried out to facilitate the participants' capability to keep track of their different units. Furthermore, to provide additional support for situation apprehension, outcome prediction, apprehension of intentions, decision-making, and coordination, two representations of intentions were implemented (figure 5.6).

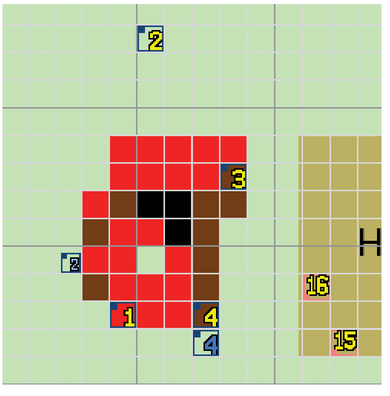

Figure 5.6. A cropped screen shot depicting the new symbols for current position (yellow) and intention (blue). Observe the resemblance between the units 1 to 4 who belong to the same group. Their belonging is indicated by the placement of the small blue square in the upper left corner. Unit 15 and 16 have a pink square in the lower left corner. These markings indicate the units' belonging to a different participant. Also, notice that the symbol of intention for unit 2 is smaller than other symbols. This indicates that it is unlikely that unit 2 will arrive in time to extinguish fire in the particular cell.

Before the team sessions, the participants completed individual training sessions. The results from these sessions were used to systematically select the commanders for the conditions of directive command and command by negation.The experimental procedure was conducted as depicted in figure 5.7.

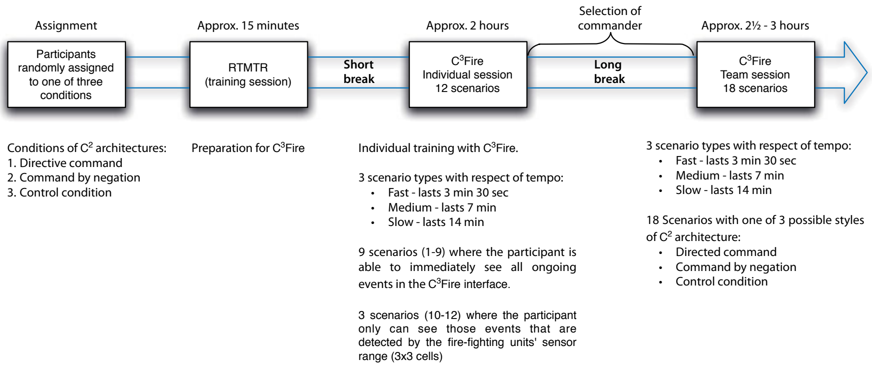

Figure 5.7. The experimental procedure.

The study used a 3x2x3x3 (C^2 architecture [directive command, command by negation, control condition] x number of controlled units [4, 16] x tempo [slow, medium, fast] x training [scenario type 1-6, scenario type 7-12, scenario type 13-18]) of trials factored design with repeated measures on the three last factors. However, as the last block of trials (training) was not part of the analysis the design was conducted as a 3x2x3 design (C^2 architecture [directive command, command by negation, control condition] x number of controlled units [4, 16] x tempo [slow, medium, fast]). Thus, the design was conducted to a 3 x 2 x 3 split-plot design with the independent variable C^2 architecture between groups. The other two and within group independent variables were thus, the number of simulated units under two conditions and tempo under three conditions.

5.4.2 Results and conclusion

Unfortunately, an unexpected error in the C^3Fire log routine caused that no data were captured under six of the 324 team scenarios. The missing data were replaced with cell mean values. When comparing the performance between directive command and command by negation under the condition of four simulated units and slow and medium tempo, the results showed no statistical differences in performance. Both the C^2 architectures showed statistical significant differences with the control condition. However, when the tempo was increased to fast, a point was reached where the C^2 architecture of directive command showed no statistical difference with the control condition. Thus, the condition of directive command did not perform better than the control condition without a C^2 function, which supported the hypothesis that command by negation is more resistant to complexity than directive command.

Under the condition of sixteen simulated units and slow tempo, the result showed no statistical differences in performance between the two C^2 architectures of directive command and command by negation. By an increase of tempo to medium, the C^2 architecture of command by negation could mobilize enough requisite variety to handle the complexity and still exercise C^2. This was, however, not the case for the C^2 architecture of directive command that did not perform better than the control condition. Again, the hypothesis was supported that command by negation is more resistant to complexity than directive command. By a further increase in tempo to fast, both C^2 architectures of directive command and command by negation performed equally poorly as the control condition. Accordingly, neither of the C^2 architectures command by negation or directive command could mobilize enough requisite variety to exercise C^2 effectively.

In this experiment, new means of graphical support was provided in C^3Fire to facilitate the participants' apprehension of current situation; needs for coordination; perception of intentions; and to reduce their cognitive and perceptual load. However, as the channels for mediation of information was designed to accomplish ecological validity, both limitations and additional possibilities in the different conditions might have contributed to effects that current experiment was less suited to manage. Considering the systematic selection of the most individually capable person as a team commander, it does not seem like a plausible causing factor for a worse team performance in either of the C^2 architectures.

In conclusion, the results from the experiment indicate that the condition of command by negation can be a more efficient C^2 architecture than directive command. This conclusion is valid at least under circumstances of complexity created by an increased number of subordinate units and medium tempo. The results do not; however, support the strong effects as proposed in the literature where it is suggested that networked C^2 architectures should provide a more effective form of C^2 (Alberts et al., 2001; Alberts et al., 2000; Alberts & Hayes, 2007; Arquilla & Ronfeldt, 2000; Cebrowski & Garstka, 1998; Potts, 2003). Moreover, considering that C^2 is equally poorly performed under all conditions with many subordinate units and fast tempo, the results are not automatically realizable. Finally, the importance of graphical representations has to be further investigated.

6. Conclusions

After five years' work I allowed myself to speculate on the subject, and drew up some short notes; these I enlarged in 1844 into a sketch of the conclusions, which then seemed to me probable: from that period to the present day I have steadily pursued the same object. I hope that I may be excused for entering on these personal details, as I give them to show that I have not been hasty in coming to a decision.

Charles Darwin

6.1 Summary and discussion of the results

The scope of this thesis was to illuminate, investigate, critically dissect, and assess selected assumptions made within contemporary perspectives of military theory how future technologies actually affect performance of C^2. This was preceded by the overall research question presented in section 1.2. Because of the complex purpose several studies were conducted with use of different methods. In the context of military C^2, collaboration among individuals with different expertise plays an important role to achieve the objectives for a military operation. The needs for understanding what new technologies can provide to support such work thus can be crucial. This thesis contributes to address these needs. However, from the vast number of claims and assumptions possible to extract from literature, only a selection of those has been addressed under this study. This selection is of course based on my individual and my coworkers' interest of research. Accordingly, there are several areas that have been unattended. From the twelve claims and assumptions listed on page 24, number 6, 8, 9, and 11 have been left aside. Most especially, this is against following background:

- An experimental comparison of speed of command was excluded. Scenarios and their extent in time were equal under corresponding but different conditions. This procedure was chosen in favor of manipulating the tempo of environmental changes (dynamics) over time.
- Under the experiments, the "adversary," embodied as a simulated fire, could not affect the survival of fire-fighting units. Thus, the measure of survivability under different conditions was not investigated.

- The inquiries, with exception of the first observation study, can be regarded as single-sided. Since the first study lacked a control group, differences in "information superiority" were not possible to observe. Nor did the design of the experimental studies allow to address this issue.

Both the ROLF 2010-vision and the concept of NCW are founded on claims and assumptions made by advocates representing the contemporary field of military C^2. However, from the analysis of theoretical views that form this field, it becomes apparent that a scientific theory of C^2 is absent. At least from providing inferential power that meets Popper's proposal to adopt falsifiability as criterion for deciding whether a theoretical system belongs to empirical science or how it withstands tests (Popper, 1959, pp. 78, pp. 251). In addition, proposals and assumptions made regarding future operational and C^2 environments put much faith in networked and technology oriented solutions. Despite that, the scientific field of contemporary military C^2 provides views, theoretical frameworks, and models that can give support for both scientific inquiries, explanations, and design purposes.

The results from the initial observation study showed that available technology did not have any effect on the work practices as expected in the ROLF 2010-vision. Although this was noticed and discussed in the article, an additional explanation to the result could be derived from how the ROLF 2010 project was pursued. As put forward in the first article, innovative technology and work environments are mainly produced from a top-down perspective. Furthermore, it is put forward that innovative use of technology and development of suitable practices occurs from a bottom-up approach. From this latter approach, contradictions between desired and actual technology use often become clear. During the emergence of the ROLF 2010-vision, considerations were made regarding development of appropriate working procedures supported by novel ICT. (Brehmer & Sundin, 2005; Sundin & Friman, 1998, 2000). These considerations could have been utilized to develop preliminary and formalized working procedures in parallel with implementation of novel technologies in the SNDC C^2 laboratory. However, the ROLF 2010 project failed to develop such work procedures, which might have contributed to the observed clash between "old practices and new technology." Otherwise, the result might not have been so apparent.

Additional remarks are possible to make that not was addressed in the first article. The training session was the first observation study made in the SNDC C^2 laboratory. In addition, only one team and no control group was used. From this follows that it is not possible to determine what actually was accomplished in terms of performance. Moreover, the actual communication and communication patterns from personal work stations were not analyzed. Accordingly, crucial information for a complete situation assessment could have been widely distributed. Hence, it is not possible to make conclusions about the team's common view of the situation. Finally, the effect of extra training before the exercise is and cannot be explicitly addressed. The reason for this is again resulting from the lack of a control group or other means of comparison. The observation study provided results and experiences of what happened under a training session in the SNDC C^2 laboratory. However, as pointed out in section 3.5, qualitative studies often are too general to provide means of measurement and quantitative evaluation. Moreover, training sessions suitable for observations at the SNDC is given once a year at best. To handle this situation, an experimental setting was needed that could provide the main features of an assumed future C^2 environment as described by the ROLF 2010-vision and the NCW concept.

From reviewing earlier research within the field of dynamic decision-making (e.g., see Brehmer, 1991, 1992, 1995, 1998; Brehmer & Dörner, 1993; Brehmer & Svenmarck, 1995; Dörner, 1980; Svenmarck, 1998a, 1998b), the results suggested that an analogous approach could be used to fulfill our needs for a controlled experimental setting and collection of quantitative data. From our purposes, we decided to put up the C^3Fire microworld for test and further development. The progress of developing methods for data collection and evaluation of the C^3Fire microworld is reported and discussed in the second paper of this thesis. The experimental design was based on claims and assumptions made in the ROLF 2010-vision and the NCW concept. Between the two conditions of the experiment in this study, no statistical significant results were provided. However, and most important, the main conclusion was that microworlds like C^3Fire are possible to utilize for simulating and investigating visionary and future properties of, for example, alternative forms of organizations, means of communication, command structures, user interfaces, and novel technology in a C^2 setting.

The third paper in this thesis was aimed for suggesting a method to psychometrically measure a commander's ability to perceive, interpret, understand, and maintain awareness of a situation to be able to stay in control of it. The experiment reported in this paper was based on assumptions made within the ROLF 2010 project and the concept of NCW where increased availability of information will increase C^2 performance. Accordingly, there was a need for a method that could capture to what degree a situation was perceived, understood, and how well it was managed. The method suggested was an alternative to the commonly used concept of SA as proposed by Endsley (1988, 1995a, 1995b). Again, the C^3Fire microworld was used as a tool for controlling the experimental setting and collection of quantitative data. In addition, data were collected with use of Logitech io™ pens. The combination of tools for capturing data showed to be useful to measure the suggested concepts of situation apprehension and outcome prediction. From the results of the experiment it was concluded that the suggested method to measure the complex mental activities and overlapping cognitive processes that are involved in decision-making, understanding, and upholding control over a situation were psychometrically acceptable. This was a satisfactory result and constituted a promising alternative to methods for measuring the concept of SA as suggested by Endsley (Endsley, 1988, 1995a, 1995b). In addition, the measuring technique that was developed in this experiment also provided predictors that can be used for measurement of performance in C^3Fire. Moreover, our suggested approach; however not discussed in the paper, do not consider individuals merely as passive recipients of data or information, which is put forward by Artman and Garbis (1998) and Bedny and Meister (1999) as critique towards Endsley.

The aim for the fourth paper in this thesis was to investigate assumptions and claims suggesting that networked C^2 architectures would provide significantly better conditions to exercise C^2 and lead to better overall performance solving a task than traditional C^2 architectures. When the experiment was carried out it had been preceded by a comprehensive pilot study. The experiences from the pilot study were utilized to further develop the C^3Fire user interface and configuration possibilities to meet the demands for the experimental design. Among the changes of the C^3Fire user interface was the implementation of different colors to separate each unit's belonging to each participant. Accordingly, this change was supposed to facilitate the capability to keep track of both own and surrounding participants' units. Furthermore, to provide additional support for situation apprehension, outcome prediction, perception of intentions, decision-making, and coordination, symbols were implemented that dynamically changed their size depending on the distance from a current to an intended destination.

The results provided by this experiment indicate that the strong effects proposed in the literature, where networked C^2 architectures should provide a more effective form of C^2, were not supported. Nor were they automatically realizable since automatic adaptation was not accomplished even in the simplified simulated environment that was used during the experiment. The task environment provided by C^3Fire was configured to create situations of increasing complexity to capture the different C^2 architectures' resistance to such conditions. Although, and maybe not surprisingly, increased complexity *does* affect performance and that no matter what system that is put up to test. Inevitable, and according to Ashby's law of requisite variety, both the C^2 function, and its organization will reach a point where available means of handling continuously increasing variety is consumed.

Although development of appropriate working procedures and processes can be viewed as a natural part when designing systems, such considerations were omitted when training the participant's for the experiments with C^3Fire. Thus, this circumstance might be considered as a confounding variable. An additional analysis that was omitted under the last experiment reported here; however, put forward as a possibility under the evaluation of the C^3Fire microworld (paper II), was the analysis of the content of messages. Such analyses might have provided additional insights. For example, to discover changes or preservation of tactical behavior that might have affected appropriate utilization of available means to accomplish the assigned task.

For fulfilling the overall purposes in this thesis, mainly the C^3Fire microworld was used and continuously developed as a tool to provide additional needs for control, collection of data, measurements, and various experimental settings. However, some drawbacks could be noticed during the developmental phases. For example, the C^3Fire microworld is a rather complex and extensive application. Hence, to meet desired demands further development, changes, and testing of new solutions became time-consuming. Accordingly, to maintain tempo between investigations was difficult. In addition, the C^3Fire microworld was externally developed, which implied that circumstances occurred that sometimes led to further delays. Nevertheless, the C^3Fire microworld proved to provide necessary functionality to mimic technological properties not available at the time. In addition, the C^3Fire microworld admitted to simulate several conditions to evaluate assumptions of C^2 environments and, most important, providing means to investigate different C^2 and organizational architectures with several levels of command.

6.2 Concluding discussion

Until recently, few studies have been conducted that address test and evaluation of statements and assumptions related to C^2 and overall performance in NCW like environments why this thesis contribute to such needs. Hitherto, the lion's share of studies has been focused on how to create and evaluate technical solutions supposed to meet envisioned properties and functionality. Although studies of teams can be considered as conducted frequently, such studies most often are performed on small teams consisting of two people who shall solve a task in some distributed environment. In addition, these kinds of studies mostly are focusing on task performance that not are addressing performance of C^2. Exceptions are however found where Rothrock, Cohen, Yin, Thiruvengada, and Nahum-Shani (2009) can serve as an example. Yet, their study does not address exertion of C^2 for larger organizations composed of different entities and with several levels of command. A rough overview outlining different areas and characteristics that can influence the capability to execute C^2, the efficiency of the controlled organization, and overall performance is depicted in table 2.2. However, the number of these characteristics is easily possible to increase depending of different objectives, perspectives or interests. In addition, studying an outcome in terms of performance from the interplay between humans and envisioned technology can also be considered a problem on its own. To obtain answers as pros or cons where an assumed technology is provided mainly leaves to take two courses of action. On one hand, it is possible to wait until the new technology is available. On the other hand, alternate solutions can be developed and prepared where the properties of the technology of interest is mimicked. The first choice might imply that the time for development and implementation of the technology will not be available within the foreseeable future. Accordingly, to perform necessary studies might not be possible in desirable time. In this thesis the latter alternative was chosen, which however involved other problems. For example, to create access to an appropriate tool that has the ability to mimic made assumptions of desired technological characteristics.

Performing the main study of this thesis, methods used for processing and analyzing data have been developed. Those methods have admitted analysis where both individuals and systems have been used as unit of analysis. The former basically to critically assess the commonly used concept of SA. This resulted in a promising method to measure performance of the complex cognitive processes that are involved in understanding and acting on a dynamically evolving situation. The latter was developed and used to measure both individual and system performance viewed as a whole under different conditions of C^2. The results from applying used methods have been found suitable for mirroring to what degree human and technology have been complementary when handling situations with different levels of complexity. In addition, the methods have been found in accordance with the used theory and capable to provide results according to specified criteria for measurements.

The use of the C^3Fire microworld has been found appropriate for comparing different conditions of C^2 situations. Thus, for the purpose of this thesis the C^3Fire microworld provided a basis to further develop methods for gaining experience and understanding of C^2 in a visionary setting, as well as means for observation and measurement under different experimental conditions. Furthermore, the C^3Fire microworld has provided means of evaluation in accordance to the PACT–FICS theoretical framework and criteria addressing design objectives. Hence, microworlds like the C^3Fire have proved to provide means and possibilities considered required both for sufficient control and for collection of data during experiments of C^2 performance under different conditions.

The PACT–FICS theoretical framework provide means for considering the need to balance and design technology with human capabilities. Thereby the work can be distributed in a way that the two parts yield positive outcomes. In addition, STS and open system theory can provide valuable input for that purpose. As put forward in section 6.1, development of suitable working procedures and processes was omitted under the development and implementation of the ROLF 2010-vision. In addition, this was also the case when performing the experiments with the C^3Fire microworld. Accordingly, a balance between decision-making processes and other activities were not explicitly addressed to support C^2 activities. However, the interplay between human and technology seems seldom be studied to find the most efficient and complementary balance between the two. The research team formed by Salmon, Stanton, Neville, Walker, Jenkins, Baber, et al., represents however, an exception and address issues closely related to those presented in this thesis. Their studies are mainly based on communication and social network analysis (SNA). Thus, performance measures and results presented here are not immediate comparable, but can definitely be combined to gain new insights.

In sum, from the overall research question and objectives in this thesis, its scope can be considered fulfilled. The empirical results can be synthesized as follows. Several assumed properties of future technologies proposed by contemporary military theorists and how such properties actually affect performance of C^2 have been evaluated and assessed. The general conclusion is that the strong advantages when technologies with future characteristics are available can be questioned. Hence, several claims and assumptions made by advocates of the ROLF 2010-vision and the concept of NCW regarding positive effects of technology seem too exaggerated. However, under conditions with moderately increased levels of complexity characterizing the situation, access to novel technologies, and that suggested C^2 architectures is implemented seem to provide advantages compared to traditional equivalents. Furthermore, the result from the qualitative observations indicates that traditional and incorporated working methods are used regardless introduction of novel technological means. To deal with this, development and implementation of novel technologies suggest that development of new working methods is required in parallel. This is in line with the PACT–FISC framework, STS, and open system theories where human and technological benefits should be balanced to complement each other and to achieve their appropriate utilization.

From the experiences acquired by the empirical studies in this thesis, the phenomenon of complexity in the context of executing C^2 calls for extra attention. It seems obvious that complexity and Ashby's "law of requisite variety" are interdependent (cf., section 1.2 and 5.4). The results from the experiment presented in the fourth article included in this thesis suggests that a level of complexity was reached where neither the networked nor the more traditional C^2 architecture performed better than the control condition which completely lacked C^2 capability. This gives rise to the long valid question how complexity, and thus variety, can be more efficiently managed. One possible answer to that is by providing novel and better technology that can supervise, manage, and used to mitigate its effect. Another can be to increase an organization's capacity to handle variety by increasing the number of people who have this task, or a combination thereof. The work conducted here has not explicitly addressed this issue, but can certainly form the subject of further studies.

Approaching and studying futuristic phenomena based on assumptions with strong arguments is afflicted with several problems. By considering the meaning of "futuristic" implies that the conditions that are of interest to investigate probably do not exist in real life. Creating necessary prerequisites by appropriate simulations can however, provide means for scientific inquiries of such conditions. It has been apparent that tools like the C^3Fire microworld possess properties that can be utilized to simulate and provide general conditions that are of interest to study and evaluate. In addition, microworlds provide means of control and collection of data from several variables. Furthermore, microworlds also provide possibilities to perform observations to collect and interpret qualitative data. For example, different patterns of behaviors. The possibility to collect various types of data from different variables can however, imply difficulties to make correct interpretations. Thus, if too much complexity is provided by the microworld it can be difficult to interpret and understand the variables and what actually has happened. However, by the possibility to combine collection of both qualitative and quantitative data as suggested in the second paper, new insights might be achieved.

Training of participants is important to avoid unwanted effects when conducting experiments with microworlds. Experiences and understanding of different phenomena studied during the progress of this thesis counsel this need. In addition, unexpected areas have been discovered that could have affected the results by different or additional training. One such possible area is the development and training of working methods that were adapted to efficiently utilize properties of novel technologies. Unfortunately, neither the ROLF 2010 project, nor the concept of NCW has developed or provided examples of working methods that can be utilized in combination with novel technology to increase overall performance of C^2.

Tools and measurements developed for evaluation have been found suitable for the progress of this thesis. However, the C^2 environment used to mimic real world situations have been conducted in a laboratory setting, which imply that the results should be treated as such. Accordingly, it is not obvious that the results can be applied to real life situations. Nor is it applicable to generalize the results beyond defined limits circumscribed by the definitions and the scope of the PACT–FISC framework used in this thesis. In practice, the reported findings from the work conducted in this thesis thus have to be further evaluated in relevant and real-life settings before predicting performance of exerting C^2, the efficiency of different C^2 architectures, design of appropriate organizations, and final implementation of technological solutions.

6.3 Suggestions for future work

The work in this thesis began as a much needed investigation to gain experiences and understanding to perform evaluations and critical assessments of assumptions made by visionaries and contemporary military theorists. The results indicate that traditional and incorporated working methods are used regardless introduction of novel technological means. Thus, an immediate challenge is to consider how new working methods can be developed in parallel with development of novel technologies. An additional challenge is to combine these working methods that promote the balance between human and technological abilities in a complementary way. There are several areas that are apparent for future efforts where some issues for research are listed below.

- Further development of tools and methods to measure situation apprehension and outcome prediction as defined in this thesis.
- Additional development of appropriate and efficient interfaces and graphical symbols that promote situation apprehension and outcome prediction under complex and dynamically changing conditions.
- Further experiments with the C^3Fire microworld or equivalent where qualitative data from audio-/video recordings and different channels of communication are analyzed according to SNA methodology (e.g., see Stanton et al., 2006). The results from these inquiries compared with data and results from live events can contribute to increase the ecological validity of microworld studies. Moreover, the results can contribute to development of additional microworlds for C^2 studies.
- Development of methods to achieve a better balance between implementation of technological innovations and proper work procedures adapted for suggested technology. Thereby, it could be easier to achieve desired objectives and better technology exploitation.

7. Summary in Swedish

Som svar på tekniska framsteg, särskilt inom fältet information och kommunikationsteknologi (IKT), uppstod den så kallade revolutionen i militära angelägenheter (RMA) och senare konceptet nätverksbaserad krigföring (NCW). Det senare har efterhand utvecklats till en teori om hur teknik kan utnyttjas för att effektivisera militär ledning. Bland förespråkare för nätverksbaserad krigföring har antaganden gjorts om hur genomförandet av framtida uppdrag kommer att kunna förbättras och effektiviseras med stöd av framtida teknik. Till exempel antas framtida teknologier kunna; öka förståelsen för en rådande situation och dess fortsatta utveckling, medge att tempot i vilket ledningen bedrivs kommer att kunna ökas samt medge att nya och mer effektiva organisationsformer kommer att kunna utnyttjas. Det övergripande syftet med denna avhandling är att kritiskt analysera och bedöma några av de antaganden som gjorts inom ramen för den svenska ROLF 2010-visionen samt konceptet för nätverksbaserad krigföring.

I avhandlingen ingår fyra artiklar. (1) En observationsstudie av en militär stabsövning genomförd i Försvarshögskolans ledningslaboratorium. (2) Resultatet från en studie där en mikrovärld använts som ett verktyg för att undersöka effekterna på ledning där egenskaper hos ny teknik införs. (3) En experimentell studie där en metod introduceras för att mäta olika individers förmåga att uppfatta och bedöma en situation och dess troliga utveckling. (4) Slutligen presenteras ett experiment som syftar till att utvärdera antaganden om olika ledningsarkitekturer och deras effektivitet samt effekter av grafiskt stöd för kommunikation.

Den allmänna slutsatsen är att de antaganden som görs där starka fördelar skall kunna uppnås genom implementering av ny teknik kan ifrågasättas. Resultat från de kvalitativa observationerna indikerar att traditionella arbetsmetoder används trots att teknik med nya egenskaper har införts. Resultaten visar att de starka positiva effekter som nätverksbaserad och teknikstödd ledningsarkitektur förväntades ha generellt inte kunde påvisas experimentellt. Emellertid visade det sig att en sådan ledningsarkitektur kan ge vissa lednings- och prestandafördelar jämfört med traditionella motsvarigheter i situationer med måttligt förhöjd komplexitet. I situationer med kraftigt höjd komplexitet visade det sig att vare sig den nya eller den traditionella ledningsarkitekturen var effektivare än kontrollbetingelsen som saknade ledning.

Nyckelord: beslutsfattande, effektivitet, ledning, mikrovärld, militär, människa-datorinteraktion, nätverkscentrerad, samarbete, team

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