Joint control in dynamic situations

by

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Abstract

This thesis focuses on the cooperative and communicative aspects of control over dynamic situations such as emergency management and military operations. Taking a stance in Cognitive Systems Engineering, Decision making and Communication studies, the role of information systems as tools for communication in dynamic situations is examined. Three research questions are examined; 1) How new forms of information technology affects joint control tasks in dynamic situations, and how/if microworld simulations can be used to investigate this. 2) What the characteristics of actual use of information systems for joint control are in dynamic situations? 3) What the pre-requisites are for efficient communication in joint control tasks and especially in dynamic, high-risk situations?

Four papers are included. A study performed with a microworld simulation involving military officers as participants is presented, and the method of using microworlds for investigating the effects of new technology is discussed. Field observations from an emergency call centre are used to exemplify how information systems actually are used in a cooperative task. An interview study with military officers from a UN-mission describes the social aspects of human-human communication in a dynamic, high risk environment.

Finally, an elaborated perspective on the role of information systems as tools for communication, and especially the relation between the social, organisational and technical layers of a joint control activity is presented.
Acknowledgements

To only put one name on the cover page of a thesis is a gross lie. Anyone doing research knows that the contents that are presented in a book like this is the result of a joint effort. There are a number of persons that I am indebted to which have contributed in different ways during the last five years.

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¹ Se http://www.ida.liu.se/~bjojo/nonac.htm
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To put this thesis into context, I first of all would like to clarify the premises. My thesis project has been financed by the ROLF\textsuperscript{2} 2010-project. The ROLF-project is a part of the Swedish effort to transform the armed forces into a network-based organisation. The entire thesis project has therefore been focused mostly on the military field, although simulations of “civilian” tasks have been used in some of the articles that follow. The discussions in the text below thus often use examples from the military domain, although I prefer to think of the studies and results as a contribution to the area of joint\textsuperscript{1} control over dynamic systems. I have tried to use “neutral” terms as far as possible, although the reader is advised to keep the military influence in mind.

This thesis mainly concerns two issues; the process of controlling a dynamic system from the point of view of a commander/decision maker\textsuperscript{4} in an or-

\textsuperscript{2} ROLF is an acronym for Rörlig Operativ Lednings Funktion, Joint Mobile Command and Control Concept.

\textsuperscript{3} By “joint control” I refer to situations that involve more than one individual in order to be controlled/managed. A more elaborated definition of control and joint systems can be found in chapter three.

\textsuperscript{4} Later in the text, I will mostly refer to persons working with these tasks as “controllers”, since the purpose of commanding/making decisions is to achieve control over something. This is elaborated in chapter three. On occasions, I will however use terms like decision maker or commander depending on the topic currently being discussed. These three terms can in this text be seen as compatible.
ganisation, and the effect new forms of information technology have on this task. My focus when conducting the work that has lead to this text may have changed over the years, but when I look back and try to identify what the central issues have been, I constantly come back to these two issues. When a human being tries to control an organisation with the purpose of controlling a third phenomenon, which in addition can be described as “dynamic” (Beyerschen, 1993) in the context I am interested in, he or she is facing “the problem of finding a way to use one process to control another process” (Brehmer & Allard, 1991). The task puts some interesting demands on the controller. It is not enough to understand how the third process, the actual target process works, the controller also has to have the ability to understand the organisation, the persons, the equipment and the systems they use to achieve this. This task is certainly very different from the more thoroughly investigated task of process control where an operator tries to control a technical system. In the perspective of a commander trying to exercise control over a target system via subordinates, the implicit expectations and understanding of social interaction suddenly emerges as a very important factor. McCann & Pigaeu (2000) states that “only humans command”. Machines, rules, barriers etc may control and regulate things, but it is the human in the system that really has the ability to handle the unforeseen and thus the only one that can make system behaviour adapt in the true sense5. The texts included in this collection (a complete list can be found under heading 1.2) thus concern how humans behave when they work together in teams, facing a dynamic situation. The focus of the thesis is described under heading 2.5.

When writing the background to the collection, I have, to some extent, used material that has been published previously. Especially those who have read my licentiate thesis will recognise parts of it in the theoretical background. I have only made some changes and additions where I found it necessary. Some parts of the text have also occurred in papers that are not included in this thesis. Under heading 1.3, the reader will find a list of my other publications that have been important during the work with this text.

5 Surely, there are artificial intelligence systems available today that can adapt to its environment to some extent. This is however not what I mean what adaptation in the “true” sense, since such a system sooner or later will face a situation that the designer could not foresee (unless you close it into a very limited space, like a simulation).
1.1. Reading instructions

This thesis aims at describing the role of information technology in joint control of dynamic situations. The work presented in this thesis should by no means be seen as a finished product, at least not in the sense that this is the end of the line. Rather, it should be read, and especially this text, the introduction, as a status report of my current view on the issue of control over complex systems. To my experience, a thesis, and especially a collection of papers, is often a showcase of the questions that have been encountered since the PhD student began his/her studies. Writing the introduction to the papers is the hard task of trying to understand one's own development over the years spent doing the research and formulate it into something consistent. I leave it to the reader to judge if I have managed to do this or not. Now some points concerning the text that follows.

The “Introduction” (chapter 2) briefly presents the area of interest and the research issues that I have addressed in the papers included in the collection. It is here that the areas of interest are presented.

The “Theoretical Background” (chapter 3) should be seen as a status report on how I view joint control over complex systems. The chapter especially focuses on how humans interact with each other when they are facing a control task. Key words are control, dynamic systems, complexity, joint cognitive systems and communication.

The “Summary of studies” (chapter 4) is mostly there for those who do not wish to read the papers in the collection. The observant reader will notice that there are discrepancies between the papers and the theoretical background. This comes from the fact that some of the papers were written in the early phase of my PhD-studies, and my theoretical approach has gone through some, maybe not fundamental, but none the less, changes. In the following chapter, the results from these studies are discussed in relation to the theories presented in chapter three.

The “Conclusion” (chapter 5) is a short summary of the theoretical background and the findings from my studies and some overall thoughts about them, and at last, a suggestion and motivation for future research. The reader who wishes to get a quick overview of this work may very well only read the “Introduction” (chapter 2) and this part.
1.2. Included Publications


1.3. Related publications


2. Introduction

The ability to communicate about abstract and concrete matters is the basic human ability that allows us to organise ourselves. This is what makes it possible to form social groupings and/or even countries. Communication made it possible to build artefacts like the Chinese wall or the Pyramids long before the machines that exist today were invented. Solely with the aid of simple devices like rods and ropes, thousands of people worked together to realize visions that were described to them without the aid of modern information technology, probably only as simple sketches and as word by mouth. Other forms of “information technology” aimed at supporting work in organisations have also been used. The Romans used a public mail system, the cursus publicus, which allowed them to keep their society together for hundreds of years. Many types of simple communication systems like smoke or sound signals have been used frequently during the last millennia. The ways to communicate over distances evolved over the centuries and with the introduction of electricity and the technologies associated with it, the telegraph and the radio came into frequent use. A great change occurred with the introduction of the digital computer, which allowed us not to only distribute, but also store data and perform computations upon it with a
much higher capacity than any human can perform. Today, we rely heavily on digital information technology\textsuperscript{6} when planning and organising work.

Humans have always strived to create better systems and societies in which we can live in an orderly and predictive way, even though the norm that makes up what an orderly way consists of is different around the world. Being a member of a society is helpful since it makes it possible to understand and predict events in everyday life. Regularity and stability in form of laws, social rules, religious practices and similar structure the way we live. The average citizen knows what is expected of him or her and tries to adapt to this in order to be a good member of the society, or in other terms, a part of the system.

Humans, and the societies they form, are sensitive to changes in their everyday environment, and therefore societies that can afford it try to prepare for unwanted deviations from the state-of-affairs that the society desire. Such preparations come in many forms, on high level in the form of an army that shall prevent intrusion from other societies, or a crisis management organisation that aims at preventing big accidents/disasters or be able to minimize the damage of such. On a more local level, most countries have police, hospitals and fire brigades to deal with things that can disturb order. Police handle citizens that do not act in accordance with the laws of the society, the fire brigades try to minimize the physical damage of fires and similar unwanted events, and hospitals try to assure that the members of the society stay healthy and productive as long as possible.

Communication is the glue that makes all of this work. If an orchestra playing a piece is going to make a successful performance, the musicians have to be able to understand the notes as well as the signs of the conductor. By understanding the notes, the musicians know what to play, and by observing the signs from the conductor, they can change their way of playing so it fits the conductor’s vision. When they do this, they behave as a system striving towards a shared goal, namely to play their individual instruments in such a fashion that the collective effect is an enjoyable performance. The same condition applies for a soccer team or a team of surgeons. The impor-

\textsuperscript{6} The term “Information Technology” will be discussed below. The term is traditionally used to describe a system meant to \textit{inform the user}, thus presenting data that is meaningful for the user. A watch can thus be seen as information technology as long as the user knows how to interpret the position of the hands, but not otherwise. The term is thus slightly misleading, since “information” always is interpreted data, and few things can be seen as information for \textit{any} person at \textit{any} time.
tant difference between an orchestra playing a symphony and a team of surgeons is that the “notes” that the surgeons “play” by are less well defined, and that they rarely know when they have to start playing (apart from the fact that they only work during certain hours). While the members of the orchestra rehearse and have full access to the notes before playing, the surgeon rarely knows who the next patient is going to be and from what he or she suffers. The surgeons work in a dynamic context. Brehmer & Allard (1991) have described dynamic work as characterised by the following points

1. It requires a series of decisions.
2. These decisions are not independent
3. The environment changes both spontaneously and as a consequence of the decision-maker’s actions.
4. The time element is critical; it is not enough to make the correct decisions and to make them in the correct order, they also have to be made at the correct moment in time.

In order to help the surgeons, or anyone working in a dynamic situation that includes high risk, predict and organise their work to some extent, various forms of information systems are available. Emergency call centres, ambulance personnel and the staff of the hospital normally make an initial assessment that is communicated to the doctors through one or more information system(s). During the time from which the hospital is alerted that a patient is in need of care until the patient actually arrives, the surgeons have to try and assess what they will have to do, and this assessment is largely based on the information they can get from other persons via the information system and their own experience/competence. Below, I will elaborate on what I mean by communication and especially communication that is mediated via technical systems.
2.1. What is mediated communication?

A brief introduction

Communication can, from a strictly technical point of view, be described as the act of transferring data from person/machine A to person/machine B with the intent of getting B to receive the message in the same form as A intended to. A naive view is that this is the same thing as communication. This is often referred to as the “conduit metaphor” (Reddy, 1993). Communication between humans is however more than the mere act of sending and receiving signs, symbols or other data. Meaningful communication is not only about transfer, it is trying to make someone or something to understand what the sender wants, thus creating meaning. A simple analogy is a person being in a foreign country with a language he or she does not understand. The conversations going on around him/her is only “data” that does not carry any meaning. It is when the person begins to learn the language that the data becomes meaningful, and the gibberish around the person turns into information that can be used. If the person also learns how to speak the language, he or she can perform tasks like asking for the way, order at restaurants or even become a part of that society.

An information system is the channels and mediums that are used in an organisation for communication and storage/computing of data. The communication may be over both space and time, meaning that users can be in different places and also that communication can be in-direct. The Swedish information scientist Langefors wrote in 1973 that:

“Information systems handle data to provide information”

(Langefors, 1973, pp 11)

An information system is thus a system that stores and distributes data, meaning that it not necessarily has to be a digital system. There are many examples of purely analogue information systems, although we today tend to think about information systems as a set of computers and communication technology. Communication in an information system may be direct, in real time, via voice, mail or data transfer, or indirect in terms of shared representations, databases or diaries. What is important in Langefors definition... 

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7 A more elaborated view on communication is presented in chapter three.
of an information system is that it is more than something that moves or stores data, it handles information, which is the interpreted form of data.

A more holistic definition of an information system has been formulated by Buckingham, Hirschheim, Land & Tully (1987) as:

“A system which assembles, stores, processes and delivers information relevant to an organization (or to society) in such a way that the information is accessible and useful to those who wish to use it, including managers, staff, clients and citizens. An information system is a human activity (social) system which may or may not involve computer systems.”

(Buckingham, Hirschheim, Land & Tully, 1987 pp. 18)

This definition does not fundamentally differ from Langefors above, but points out the fact that almost any configuration of humans and/or machines can be an information system, as long as it fulfils the basic demand of handling data in order to provide information. It does however lack the differentiation between data and information that Langefors emphasised in his texts (Langefors, 1973; 1993). What is clear is that the study of information systems ranges over a number of scientific disciplines like computer science, sociology, engineering and cognitive science. In this thesis, information systems are seen as tools used for coordinating activities. The role of information systems as tools for communication is emphasised in this thesis. Especially the relation between the social, organisational and technical layers of a joint control activity is put forward.

The term “communication technology” will be used to refer specifically to the technical artefacts used for communication rather than “Information systems”, since information systems often comprises a wider range of technology serving other purposes than communication. What characteristics are then important to recognise when studying control performed by jointly by several persons in dynamic situations? Below follows a brief introduction to the subject.
2.2. The context – control in dynamic, high-risk situations

Above, the characteristics of dynamic control were described according to Brehmer & Allard (1991). Dynamic situations exist in many forms, but this thesis is concerned with the handling of crisis or warfare. Normally, there are two types of organisations that have been created by society to respond to such situations, the rescue services and the armed forces. Almost all countries/societies in the world have these two types of organisations. There are some fundamental characteristics of these types of crisis situations, apart from the characteristics of dynamic systems as described above; they require large, coordinated efforts involving a vast number of people and equipment, the situation often involves high risk for physical damage to personnel or equipment, information about what is going on is uncertain, and finally, decisions about actions are rarely made by one person at one location, but is rather distributed both between persons, places and in time. Orasanu & Connolly (1993) have described eight factors that are common to these types of settings:

1. Ill-structured problems
2. Uncertain dynamic environments
3. Shifting, ill-defined, or competing goals
4. Action/Feedback loops
5. Time Stress
6. High Stakes
7. Multiple Players
8. Organisational goals and norms

(Orasanu & Connolly, 1993 pp 7)

These demands apply to civil crisis, like natural disasters, as well as for wartime operations. All of these characteristics put demands on the ability to communicate and inform people involved so that they can organize themselves and respond to the situation in an orderly fashion. What I am discussing in this thesis is thus work conducted by teams of people, which may or may not be a part of a larger organisation, aimed at handling dynamic, high-risk situations with possible conflicting goals under time pressure.

A team consists of two or more people working together towards a shared goal or objective where each participant has a specific role or function to fulfil (Waern, 1998). The term dynamic has already been described indirectly in the characteristics from Brehmer (1992) above. By dynamic systems, it is normally meant systems that change their state over time in a way that is
2.3. Information systems intended for dynamic situations

During the last twenty to thirty years, a great interest and effort has been taken into designing and introducing information systems in crisis management and military operations. Especially in the military domain of command and control (C2) (Van Creveld, 1985; Roehlin & Demchak, 1991; Johnson & Libicki, 1995; Albert, Garteka & Stein, 2000) there has been a focus on developing new information systems and decision support systems. A common argument for introducing new information systems in this area is to increase the speed and precision by which the organisation can act. The focus on this topic probably comes from the influential theories presented by Boyd (Hammond, 2001). Boyd worked as a fighter pilot for the United States during the Korean conflict, and later as a trainer and advisor for the US Air Force. The fundament of his theory was the OODA-loop (See figure 1.), which describes the task of a fighter pilot in terms of Observation, Orientation, Decision and Action, arranged in the form of a loop. His conclusion was that in a fight between two pilots in equal fighter planes, the one that is able to execute his OODA-loop faster will be the winner. This thinking has later been adopted by other military thinkers and translated to fit into an organisational perspective.
Figure 1. Boyd’s OODA-loop. Adapted from Hammond (2001).

It is believed that the mere improvement in gathering information from the surroundings could speed up the “Observe” and “Orient” parts of the OODA-loop, and this has had a great impact on the view of information technology. In combination with the galloping development of the internet and computing in general, several ideas about networked organisations for crisis management and warfare have emerged, described in the military community as a “Revolution in Military Affairs” (Chebrowski & Gartiska, 1998). The success of the coalition in the first Gulf War has also “confirmed” that these approaches are promising (Rochlin & Demchak, 1991), and several countries (like Sweden) have now stated that they will transform their armed forces into “networked” forces or that they intend to do this. The main differences between the old-fashioned military organisations and the envisioned ones are described in Table 1 below. The spin-off of the military development has also been that rescue services try to change their organisation and information systems according to similar concepts, although there still is a heavy debate within the military sector about what a “networked” force really is.
Table 1. Differences between traditional and envisioned command and control systems (Persson & Johansson, 2001)

<table>
<thead>
<tr>
<th>&quot;Traditional&quot; Command and Control-Systems</th>
<th>Envisioned Command and Control - Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Organised in hierarchies</td>
<td>• Organised in networks.</td>
</tr>
<tr>
<td>• Information distributed over a variety of systems, analogue and digital. Most common medium is text- or verbal communication.</td>
<td>• All information is distributed to all nodes in the system. Anyone can access data in the system.</td>
</tr>
<tr>
<td>• Data is seldom retrieved directly from the sensor by the decision-maker. Rather, it is filtered through the chain of command by humans that interpret it and aggregates it in a fashion that they assume will fit the recipient.</td>
<td>• Powerful sensors support the system and feed the organisation with detailed information.</td>
</tr>
<tr>
<td>• 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.</td>
<td>• Data is mostly retrieved directly from the sensors. Filtering or aggregation is done by automation.</td>
</tr>
<tr>
<td></td>
<td>• 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.</td>
</tr>
<tr>
<td></td>
<td>• 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.</td>
</tr>
</tbody>
</table>

In Sweden, information system projects are going on that aim at introducing network-like systems within the rescue services, like the RAKEL-project8 (Näringsdepartementet, 2003). One of the explicitly stated purposes with RAKEL is that not only the normal users like fire brigades and the police shall be able to use it, but it shall also provide the possibility to connect external actors in the event of larger crisis, thus creating a very large, inter-organizational communication and data-sharing network. It is evident that large investments are made in technical systems with the hope to improve security in society and efficiency in crisis management.

Many designs of information systems are based on assumptions made by technicians or in the best (?) cases by psychologists or interface design experts9. There are also infamous examples of failed attempts to create infor-

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8 RAKEL is an acronym for "Radiokommunikation för Effektiv Ledning", an attempt to integrate all the different radio systems in the different Blue-light organisations so they have the possibility to exchange data between the different organisations via radio.

9 I do not suggest that psychologists or interface designers should be excluded from the design processes. Conversely, I try to point out that these types of systems in the best cases have had involvement of such persons in the design, and even then they often fail to serve
information systems (Riksrevisionsverket, 1997; 1999) for both military and civil crisis management systems. A central question in this thesis is to understand what crisis management, or control of dynamic situations, is about and how information systems actually are used in these situations.

But why is it hard to design systems for crisis management? The answer probably does not lay on the technical side since it evidently is possible to create enormously complex systems of computers, like for example the Internet. Rather, the problem is likely to originate from the task for which the systems are created. When creating a system intended to be used in a dynamic situation, it is difficult to foresee a number of things, like the nature of the setting in which it is going to be used, who, and perhaps more importantly, which constellation of users that actually are going to use it, and the needs that emerge in situations that per definition is hard to predict. In this thesis, the focus lays on systems of humans and machines that try to control a dynamic situation. I will argue that the communicative infrastructure in a system consisting of humans and machines is made up not only of technical means for communication, but also of social and organisational structures. An important question is what effect different forms of technology have on the way that it is possible to communicate and control in a dynamic situation.

2.4. Microworlds, a tool for investigating the role of technology in crisis management?

How do we then approach the question of joint control of dynamic situations? The study of dynamic decision making has a comparatively long tradition of studying how humans cope with dynamic situations (Brehmer, 2004). This area has for a long time faced the same type of problems that the designers of information systems for dynamic situations are facing, namely that it is difficult to investigate how people handle dynamics in anything less than reality, and thus it is equally difficult to investigate the effects of new technology in anything less than reality as well. However, the field of dynamic decision making might have something to contribute in this case,
since this field has developed a special kind of computer-based simulations, so called microworlds (Brehmer & Dörner, 1993; Gonzales, Vanyukov & Martin, 2004), in order to create a situations with, from the researcher perspective, controlled and traceable dynamics. Therefore, it could be assumed that microworlds are suitable not only for investigating how people behave when they are confronted with a dynamic problem, but also for investigating the effect of new technology in relation to the ability to handle such tasks. In this thesis, the first paper reports a microworld study investigating the of new information technology on team performance. The second paper discusses how microworld simulations can be used for investigating the impact of new technology in command and control situations.

2.5. Focus of this thesis

The papers included in this thesis reports studies using mainly military officers as informants, but also personnel working at an emergency call centre.

The thesis aims at:

- Describing the role of information technology for communication in joint control in dynamic situations. This topic has been narrowed down to the following points:

  - How new forms of information technology affects joint control tasks in dynamic situations, and if/how microworlds can be used to investigate this.

  - What the characteristics of actual use of information systems for joint control are in dynamic situations.

  - What the pre-requisites are for efficient communication in a joint control task and especially in dynamic, high-risk situations?

This thesis focus on the view of humans and the artefacts they use as a system that works towards a goal with the purpose of controlling its environment. As stated above, communication, and the artefacts humans use in order to communicate, is seen as essential tools when a team of humans perform control work since control in most cases only can be achieved by coordination. Coordination, in turn, is normally achieved by communica-
tion. Two approaches are presented, experimental studies of teams, using low-fidelity computer simulations, microworlds, and 2) qualitative studies of control work with information technology from practical crisis management.
3. Theoretical background – Control, tools and communication

Fundamentally, control in an organisation, or in any system, is dependent on communication. The activity of controlling concerns influencing something or someone in one state towards another (Shannon & Weaver, 1949). In order to achieve this change, the controller needs to transfer his/her intent, either as action(s) directly on the target or as instructions/goals to the system that is to execute changes to it. In a cognitive system\(^\text{10}\) consisting of several actors, it is positive if all actors in the system share a common understanding/model of the desired state to-be-achieved so they can adjust their behaviour to reach this goal-state. This means that joint human activities needs to be more or less coordinated/regulated. This can be done in many ways and it is easy to find several every-day activities that are heavily orchestrated by cultural habits, trends, laws and explicit or implicit agreements. All control activity, or behaviour, exists in a context that in turn shapes that activity/behaviour (Neisser, 1976; Vygotsky, 1978; Suchman, 1987; Hutchins, 1995). As mentioned in the previous chapter, this thesis will focus mainly on human control since the focus concerns target systems that are less well defined and thus demand higher creativity from the controller, something we do not normally contribute to machine control.

\(^{10}\) The term “cognitive system” refers to a system that can behave goal oriented and adapt to changes in the environment. A more elaborate definition is given later in the text.
In this thesis, I present a theoretical ground based on Cognitive Systems Engineering (CSE), complemented with Dynamic Decision Making and Communication. CSE is an approach aiming at analysing and evaluating the performance of complex systems consisting of both humans and technical artefacts. The two main concepts of CSE are control and joint cognitive systems. Both of these terms will be described in detail below. Taking a stance in cybernetics, CSE has extended the basic cybernetic theories about control by taking the cognitive aspects into account. This does not mean that the focus of CSE is on cognition in the information processing sense. Rather, a basic premise in CSE is that all humans act in a socio-technical context that primarily shapes their behaviour, and thus performance. Dynamic decision making and the specific limitations of humans in dynamic control situations are also discussed, since they are an essential component of the control process. The role of communication and technologies used for communication is also discussed. In cybernetics, the intimate relation between control and communication is emphasised since cybernetics to a large extent focuses on exchange of and transformations of signals and energies (Wiener, 1948; Ashby, 1956). Communication can, from a control perspective, be described both as the act of transferring data and as the act of sharing intent or controlling someone/something. A more elaborate perspective on communication is presented below, which also concern the specific characteristics of human-human communication.

I will try to describe the connections between these fields, since they all, in some sense, depend on each other. According to Cognitive Systems Engineering it is possible to view a number of persons and the equipment they use as a Joint Cognitive System, meaning that the system as a whole strives toward a goal and that the system can modify its behavioural pattern on the basis of past experience to achieve anti-entropic ends. Decision-making is relevant since it concerns the human ability to evaluate, understand, and choose action in uncertain environments, which is a core activity in human control. If a team of humans are to function as a system that strives towards a goal originating from a decision, this goal, or intention, has to be communicated within the system.
3.1. Control

The term "control" is widely used in a range of disciplines. According to cybernetics as described by Ashby (1956), control is a state when a controller keeps the variety of a target system within a desired performance envelope. A control situation thus consists of (at least) two components, a controlling system and target system, where the controlling system is trying to control the state of the target system.

A simple example is a thermostat that is designed to keep the temperature in a room at twenty degrees Celsius. It is normally attached to a radiator. The thermostat needs information about the current temperature in the room so that it can turn the radiator on/turn off in accordance to the desired temperature. If the temperature in the room is above twenty, the thermostat turns the radiator off. If the temperature decreases, the thermostat triggers the radiator in order to increase it. This is a simple example of feedback driven regulation.

A completely feedforward driven controller could instead provide the radiator with output signals in accordance with a model of the typical temperatures of the room during a typical year, and hopefully produce some kind of temperature close to twenty degrees. Feedforward can thus exist without feedback and vice versa. However, most systems, just like we humans, work with both feedforward and feedback driven control mechanisms. The reason for this is obvious. A system based only on feedback (like the thermostat above) will only take action if a deviation from the desired state occurs. A completely feedforward-driven system on the other hand would be able to take action in advance, but would not be able to adjust its performance in relation to the system it acts upon. Feedback control examines the difference between a state and a desired state and adjusts the output in accordance. Feedforward driven controllers use knowledge of the system it is supposed to control to act directly on it, anticipating changes. Hollnagel (1998) has proposed a basic model of human control based on Neisser’s (1976) perceptual cycle. Similar models exist in different forms, like Brehmer’s Dynamic Decision Loop (DDL) (Brehmer, 2004) or Boyd’s OODA-loop (1987, see figure 2). There are also some similarities with Miller, Galanter & Pribsams TOTE-unit (1960).
Figure 2. The basic cyclic model of control (Hollnagel, 1998).

The controller, who is assumed to have a goal, a desired state that is to be achieved, takes action based on a understanding, a construct, in his/her effort to achieve or maintain control over a target system\textsuperscript{11}. This action produces some kind of response from the target system. These responses are the feedback to the controller. It is not self-evident that the observable reactions are purely a consequence of the controller’s action; they may also be influenced by external events. The controller will then maintain or change his/her construct depending on the feedback, and take further action. The model above (figure 2) will be used as a reference through the rest of this thesis, referred to as the “basic cyclical model”.

Above I have presented ad definition of control. According to this definition, control is successful if the controller manages to perform a task in accordance with a goal. When this fails, we refer to it as a deviation. But what is a deviation? According to Kjellén (1987), a deviation is the classification of a systems variable when the variable takes a value that falls outside a norm.

\textsuperscript{11} I use the term “system” in this case. It should be noted that the term “process” also could be suitable.
“All different classes of deviations are defined in relation to *norms* at the systems level, i.e., with respect to the planned, expected or intended production process. “

(Kjellén, 1987, pp 170)

Two basic elements in the definitions of deviations are identified by Kjellén, and they are *systems variable* and *norm*. A norm and a system variable can be described in different ways depending on the kind of system that is in focus. The norm is always some kind of desired state, although the definition of these states can be of many different kinds, like a discrete state or a performance envelope. The system variable/variables is/are what we gather information about in order to judge whether or not the system performance is within the desired state (see figure 3).

![Diagram of deviation](image)

**Figure 3. Illustration to deviation.** A process runs over time and is ideally kept within a desired performance envelope. The possible performance envelope is, however, almost always larger than the desired, otherwise the norm would be unnecessary. To leave the desired state at any time is considered a deviation.
3.2. Pre-requisites for control – the model condition

Construct is the term used by Hollnagel (1998) to describe the current understanding of the situation in which control is exercised, and the understanding of how the controller is to reach its goal. The notion has clear connections to terms like “mental model”, and “situation awareness” (Endsley, 1995), but it does not make any claims of explaining the inner workings of the human mind. In fact, the controller does not even have to be human. What is important to recognize is that the construct is based on competence and information given in the situation and that it is hard for the controller to distinguish the feedback given in terms of whether it is a product of the own actions or of the environment. The construct gets updated every time the controller gets feedback from the process to be controlled (or believes that feedback has been given). Brehmer (1992) states similar requirements for control:

there must be a goal (the goal condition)

it must be possible to ascertain the state of the system (the observability condition)

it must be possible to affect the state of the system (the action condition)

there must be a model of the system (the model condition).

Brehmer refers the last condition to Conant & Ashby’s classic paper “Every good regulator of a system must be a model of that system” (1970). If we do not have a good model/construct, the only solution is to use feedback regulation, meaning that we respond to changes in the target system after they actually occurred. Feedback regulation is therefore of great importance in many systems, since perfect models of real-world systems rarely, if ever, exists. By interacting with a process, a controller that initially had a poor model may learn how the process normally responds, and thus build up a model of how to control the system based on feedforward actions.
3.3. Context and complexity

*Context*, or the situation in which control is executed, can be a source of friction which proves the difference between the construct or model that the controller has and the actual development of the control process (Clausewitz, 1997). Human performance is, as pointed out above, largely determined by the situation, but also its own capabilities. The environment, our cognitive limitations, and the temporal aspects of our activities constrain the possible actions we can perform when facing a situation.

If we consider a common task like driving to work, we quickly realize that even though it mostly works out in the desired way, there are a large number of things that possibly can go wrong, and we always make several adaptations to the surroundings while driving. Other drivers, construction sites and animals are just a few of the things the have influence on the way we drive our vehicles. On the other hand, context is very necessary for driving since the limitations it provides at the same time structures the task by providing rules and norms for behaviour. Imagine driving to work without any roads, traffic rules or signs. The road has the contextual feature of limiting the area we drive on. The rules of traffic help us manoeuvre in traffic. By constantly reducing the number of possible alternatives of choice with the system of “traffic”, it becomes possible to move large and heavy vehicles at extensive speeds close to each other, with a surprisingly low accident rate. Context thus provides both structure and uncertainty at the same time. Clausewitz (1997) emphasizes the difference between “war on paper”\(^{12}\) and real war, and stressed that it is the small things that we cannot foresee that really prove the difference. Bad weather, a missing bolt, a misunderstood message or a miscalculation are all things that in isolation do not seem that serious. But a missing bolt in a vehicle can block an entire road, bad weather can delay a crucial assault on enemy lines, a misunderstood message can make the decision-maker misjudge a situation. Context is thus the current needs and constraints, the demand characteristics of the situation.

*Complexity* is a term that is commonly used in literature to describe a situation where a controller faces a situation that is incomprehensible at first sight. Although we tend to think of complex systems or complex situations

\(^{12}\) Clausewitz famous work “On War” naturally discusses warfare, but it is possible to apply his arguments on most activities that can be described abstract/theoretic and then is performed in practice.
as systems/situations that are characterized by a large set of components or events that are inter-connected/related, it is important to remember that the term complex is a relative notion. After all, a video-recorder can be experienced as “complex” although it intuitively feels like a nuclear power plant is more “complex”. There are some dimensions of complexity that should be mentioned that are helpful when describing and discussing so-called “complex” systems. First of all, the degree of **coupling**, which refers to the amount of slack or buffer in between the components or sub-processes in the system. Tight coupling means that delays are short or non-existent, and that sequences of events are invariant. Loose coupling means that processes can be delayed or even halted without great disturbances to the system as a whole. The second dimension is the **interactions**. The complexity of the interactions decides how sequential the processes in the system work. For example, a manufacturing line does not normally allow that one step in the production is left out, because the next step cannot be performed without the former. Figure 4 below illustrates these two dimensions of complexity and places some common systems within them (Perrow, 1984).

![Figure 4. Two dimensions of complexity. Adapted from Perrow (1984, pp 97).](image-url)
3.4. Human control of dynamic systems

Control, as described above, is the process where a controller tries to change the state of a target system into another state, or conversely try to prevent the target system from changing state. The term “dynamic systems” is used to describe systems that change spontaneously over time. These are the target systems that are of interest to this thesis. Non-linear means that the development of the system is subject to change in a complex way compared to the input given to it, largely depending on the preconditions in the system. Such systems thus disobey proportionality or additivity, even if they can seem to have these characteristics under some circumstances. Brehmer has described three characteristics found important to describe the problems a controller faces when trying to control a dynamic system (Brehmer & Allard, 1985; Brehmer, 1987; Brehmer & Allard, 1991):

1. It requires a series of decisions\(^\text{13}\). These decisions are not independent.

2. The environment changes both spontaneously and as a consequence of the decision makers actions.

3. The time element is critical; it is not enough to make the correct decisions and to make them in the correct order, they also have to be made at the correct moment in time.

The example Brehmer uses is a forest fire (1987). Forest fires are conceptually fairly easy to understand, but very hard to control, mainly because of the difficulties in predicting its behaviour. Will the wind for example change during the process of fighting the fire? If it does, the fire fighters have to move to a different side of the fire, a large project if the fire is wide-spread. How fast will the wind blow? The speed of the fire can cause dangerous situations for the personnel fighting the fire and will also have great implications for the logistics of the fire-fighting organization. We must not forget that the experience of a system emerges from the understanding the controller has of the target system. Even if a system actually is linear in its behavior, making it easy to predict changes, it may appear dynamic to the controller

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\(^{13}\) When Brehmer writes “decisions”, I assume that he also means that these decisions are actually transformed into actions.
if the controller lacks in understanding of the system dynamics or has a faulty understanding of the system.

### 3.3.1 Human Limitations in Control

Human decision-making in complex/dynamic situations is an essential component of control in complex system, since it always is humans who has to take over the control task in a system if something unexpected (not included in the normal/expected functionality of the regulating system) happens. Hollnagel describes a *circulus vitiosus* when a decision maker gets caught in a false understanding of a control process because something unexpected happens (1998). The basic idea is that unexpected feedback, (false, incomplete, too much, too little, too early, too late etc) may challenge the construct of the controller and thus end with an incorrect understanding/construct of the situation. This in turn leads to inadequate compensatory actions or feedforward that introduces even higher undesired variation in the system, thus giving new, confusing feedback to the controller.

From the discussion above about dynamic systems, we have concluded that decision making in this context is signified by time-pressure, inadequate or lacking information and external influence on the actual execution of control and the feedback given. Further, Orasanu & Connolly (1993) point out that decision-making in complex systems often puts even more pressure on the decision maker, since decision may, if wrong, be dangerous (for example in nuclear power plants) to a large number of persons (including the decision maker) and/or have great economical consequences. All these different factors create stress that has to be taken into account when reasoning about control in real-world systems rather than hypothetical regulation tasks or experiments.

According to Conant & Ashby (1970) and Brehmer (1987) it is necessary that the controlling system is/has a model of the system that it is supposed to control, that minimally matches the variety of the target system. Functionally, this is true. There is however some additional difficulties that we need to consider when we discuss human decision-making. The human psyche is not working in the rational way a machine does, even if we claim to study “cognitive systems”. Speaking metaphorically, the “cogs” in the cognitive “machinery” does not always turn in the right direction, something that was recognized already by Lindblom (1959) when he concluded that most human decision-makers facing complex situations rarely base
there decisions on analytic reasoning, but rather seem to use the tactic of “muddling through”. By “muddling through”, Lindblom meant that the decision-maker seems to find a few obvious alternatives and try them. This simple heuristic does not aim for the perfect solution, but rather for one that works at the moment. Thirty years later, the fields of dynamic decision-making and naturalistic decision-making are devoted to examining the psychology of decision-making under similar conditions. One of the major results from the studies in naturalistic decision-making is the theory of “recognition primed decision making” (Klein, Orasanu, Claderwood & Zsambok, 1993). The basic idea behind the theory is that a decision maker facing a problem tries to identify aspects of the new problem that have similarities with previous experiences, and tries to find a solution to the new problem from the solutions used previously in similar situations.

Another important finding comes from the Bamberg group, who has made substantial contributions to the field of dynamic decision making, or “komplexes Problemlösung” (Dörner, Kreuzig, Reither & Stäudel, 1983; Dörner, 1989). Using microworlds¹⁴ for experimentation, Dörner & Schaub (1994) have identified some “typical” errors¹⁵, or “pathologies of decision making” (Brehmer, 1992) made by decision makers when facing complex problems. The errors correspond to a sequence of phases in, what Dörner calls, “action regulation”, which is similar to the basic cyclical model of Hollnagel described above (1998), but without the circular arrangement. The sequence rather reflects a “decision event” rather than a process, but it is nevertheless interesting since the errors identified certainly can be applied to a circular model as well. According to Dörner, the pathologies should not be seen as causes of failure in themselves, but rather as behaviors that occur when people try to cope with their failures. However, Jansson (1994) promotes the idea that the pathologies actually are precursors to failure rather than ad hoc explanations. In either way, it is to some extent possible to identify the pathologies in the actual behaviour of a person trying to control a dynamic system. Brehmer, (1992) has summarized the findings of the Bamberg group, calling them “the pathologies of decision making”.

¹⁴ A simulation developed for research purposes, see below for an elaborated discussion/description of microworlds.

¹⁵ “Error” is in this case a heavily debated term. Assume that I refer to an action taking that will increase the variation of the system in an undesired way.
The first pathology is called *thematic vagabonding* and refers to a tendency to shift goals. The decision maker jumps between different goals, rather than trying different solutions to reach the same goal, which probably is more appropriate. The second pathology is *encystment*. The consequence of this behaviour is that the controller sticks to a goal he/she believes to able to achieve rather than trying to state a more relevant goal state. The third pathology is the one to *avoid making decisions*. It is claimed that ostriches use this tactic when they put their heads in the sand rather than run if frightened. A fourth pathology is *blaming others* for own failures. A fifth pathology is *delegating responsibility* that cannot, or should not, be delegated. The other way around, not delegating, can also be dangerous, especially in hierarchic organizations where feedback reaches lower levels first, implying that delegation could increase the response time of the controlling system.

Brehmer observes that the pathologies fit into two categories, the first one comprising the first two pathologies, the other one the last three. The first category concerns goal formulation. The second one, refusal to learn from experience, is naturally also important considering the basic cyclic model. However, Brehmer also notes that we know little about the regularity of these pathologies, i.e., if they are common, and we also do not know much about individual differences related to the pathologies.

To use the term “decision” can thus be seen as somewhat misleading, since it is fair to ask whether some actions taken in dynamic situations really had any alternatives. Of course the term can be used in retrospect and ask someone why he or she did something in a particular situation, but we have to remember that the answer is a reconstruction of a series of events. When we motivate why we did something, we want to give a rational explanation, but it is not always the truth.

It can be concluded from this that humans are the essential creative part in a cognitive system that can handle unanticipated events, but it is also so that the human part of the system is sensitive to a number of possible *increases* in undesired performance variation, both due to external influences that the controller is unable to understand correctly, but also because of erroneous behaviours that may occur due to human limitations.
3.4 Joint Cognitive Systems

From real world practice, it is evident that situations like the ones concerned in this thesis, emergencies, crisis and war, cannot be controlled by individuals. The signifying similarity is that they are handled by teams or even organisations of people with a number of tools that work together (Orasanu & Connolly, 1993; Brehmer & Svenmarck, 1994). Within the military community, control has traditionally been centralised by organising authority in hierarchies, but this is not equivalent to saying that the highest command is in perfect control. Conversely, they are mostly only providing directions or intents for their subordinates, since the dynamics of the environment forces commanders on lower levels to take local initiative. This means that the decision making of an armed force in practice is distributed, and that the coordination of actions often is the result of assumptions and negotiations in the current situation. The communicative aspect will be discussed below. There are numerous examples of how distribution of tasks is necessary to stay in control from other domains (Artman & Waern, 1998; Samurac & Rogalski, 1993; Hutchins, 1990, 1995). This fact introduces a new problem for the researcher, namely the unit of analysis.

A problem that most researchers concerned with real-world control tasks probably recognises is the problem of identifying the boundaries of the unit of analysis, the “system” that is of interest. Although researchers within for example distributed cognition (Hutchins, 1990; 1995) have recognised that the unit of analysis should be a system, few methods describe how to decide what the system is. More precisely, the question that needs to be answered is where the system has its boundaries in some objective way. Hierarchical breakdown is often suggested as a way to identify units in a system (Simon, 1996; Checkland, 1999). Scientists working within distributed cognition or Computer Supported Cooperative Work (CSCW) (Schmidt & Bannon, 1992) often use ethnographic methods, which mean that they often use the actual work situation as the unit of analysis. Other scientists (see for example Garbis, 2002) depart from the use of an specific artefact in their analysis. Within the field of Cognitive Systems Engineering, it has been suggested that the unit of analysis should be judged from a control perspective. Above, it has been concluded that it is possible to describe a cognitive system functionally. A system composed of one or more individuals working with some kind of technical artefact has also been described as a Joint Cogni-
In this case, man is not differentiated from machine in other terms than functions, and if man and machine performs a function, they can be viewed as one. There is thus less interest in the internal functions of either man or machine, but rather the external functions of the system (Hollnagel, in press). A problem with the “systems” perspective is to define the borders of the system. Clearly, parts of a larger system can be studied as a joint cognitive system. There is thus a pragmatic dimension when defining the border of a system. From a perspective of requisite variety (Ashby, 1956), it could be said that many systems are created as a response to the growing complexity of modern technical processes such as flight management or industrial processes. This may also lead to that systems grow more and more, since controlling (or at least supervising) the control system in itself becomes a task. In some well-defined situations, this might not be necessary, since it is possible to predict the variety in the target system so well that responses are more or less “automated”, although they are executed by humans. In other, less well-defined systems, coordination and planning are severe problems, and the organization has to spend resources on these aspects. Military systems, and organizations structured in hierarchies in general, are examples of this. The executives (soldiers and their weapons) become so many that they need to be managed to coordinate the effect of their work.

How can then the borders of a JCS be defined? Hollnagel (in press) suggests that a pragmatic approach should be used, based on the functionality. For example, a pilot and his plane is a JCS. But a plane, pilot and a crew (in a airline carrier) is also a JCS, and several planes within an air traffic management system are also a JCS.

In order to define if a constituent should be a part of the JCS, it is necessary to identify if the function of it is important to the system, i.e. if the constituent represents a significant source of variety for the JCS – either the variety to be controlled or the variety of the controller (Hollnagel, in press). The variety of the controller refers to constituents that allow the controller to exercise his variety, thus different kinds of mediators. Secondly, it is necessary to know if the system can manipulate the constituent, or its input, so a specific outcome results. If not, the constituent should be seen as a part of the environment, the context. In the case of aviation, Hollnagel states that

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16 To my knowing, the term joint cognitive system first emerges in a book chapter by David Woods (1986), although no formal definition of a JCS is included in that chapter.
weather clearly is a part of the environment rather than the JCS, since it is beyond control. If the case of a plane and its crew is used as an example, the air traffic management can be seen as a part of the environment, since the plane and its crew rarely controls the ATM. The border of a JCS is thus defined more in terms of its function than its structure or physical composition, although these sometimes are clearly related.

A JCS is thus a system capable of modifying its behavioural pattern on the basis of past experience to achieve anti-entropic ends. Its boundary is analytically defined from its function rather than its structure. The boundary is defined with an analytical purpose, meaning that a JCS can be a constituent of a larger JCS. How is it then that a JCS can achieve anti-entropic ends? This is basically the same thing as achieving goals with the purpose of staying in control. In a system comprising several components, the components have to understand what those goals are in order to adjust their behaviour in such a fashion that the goals are achieved. In the next paragraph, some concepts central to understanding how a system including human actors can do this will be introduced.

### 3.5. Norms and organisational culture

Goals and norms are central concepts in control (Kjellén, 1987). A goal is something that is needed to take purposeful action. Norms are the way we normally do something, or the value that a systems variable normally has or should have. There are some interesting distinctions that can be made between different kinds of norms and goals. A goal can for example be that a variable should be kept within a certain performance envelope. A power plant should produce a certain amount of watts per hour, not too many since it may harm the equipment, and not too few since it will not be able to supply the buyers of the electricity. The other kind is the goal referring to a limit, which declares that a system variable may not pass a given value. For example, I may not use a certain parking space longer than I have paid for. Another important distinction is what norms and goals refer to. If they refer to a discrete state, it is easy to determine deviations from it. They may also refer to something less well defined where the boundary is stretching over a continuum; a value may for example be “acceptable” although it is not perfect. In these cases it is much more difficult to determine exactly when a deviation occurs.
There can thus be a wide span of vagueness in these different definitions. In a technical regulation task, like a thermostat, the desired state can be very precise and can also be measured. The “norm”\textsuperscript{17} for the thermostat is the given desired temperature, and a deviation is any other temperature. This norm is very clearly defined and so is the system variable it relates to, the measured temperature. In other, more complex, technical systems, the norm, or steady state, may be a composition of several different variables that together define the state of the system. An important distinction to make is that while regulation, as in the example of a thermostat, is mostly based on signals, higher level cognitive activity mostly concern the interpretation of symbols or signs. Even more important, when we, as in this case, use technical regulation as a metaphor for control in large systems involving human actors, there may be few or no “signals” involved at all. The analytical level rather concern symbols or signs. The usage of terms like “control”, “norm” and “system variable” should thus not be confused with the usage of the terms within fields like cybernetics. The “norm”, or target value, in the thermostat described above is an explicitly stated “norm”. Although such values exist in many everyday activities, human action is largely shaped by \textit{implicit norms}, based in culture and practice. In a socio-technical system, the humans in the system have a very important role in maintaining “norms”, although norms tend to change with practice. In the course of practice, the persons involved will adapt to their environment and learn what type of strategies that is useful in specific situations. Schein (1984) describes this phenomenon when he defines organisational culture.

“Organizational culture is a pattern of basic assumptions that a given group has invented, discovered, or developed in learning to cope with its problems of external adaptation and internal integration, and that have worked well enough to be considered valid, and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems.”

(Schein, 1984, pp 3)

Although Schein uses “culture” instead of “norm”, the quote is useful, since culture very much takes the form of a set of norms that are specific to a

\textsuperscript{17} Of course thermostats do not have norms in the sense humans have. But we can still use it as a valuable example, since the purpose of the thermostat, the goal, is to keep the temperature at a desired level, and the “norm” for the thermostat is the reference given by its user.
certain culture (Hutchins, 1995). The “organizational culture” that Schein
describes above is thus the norms that are established in a certain organisation.
Problems often arise when organisations with contradicting
norms/cultures are to cooperate, especially in critical situations when for
example fire brigades have to work with police or military personnel (Johansson 
& Artman, 2000). Above, the concept of a Joint Cognitive System
(Hollnagel, in press) was presented. From that perspective, an entire organi-
sation could be seen as a system. If we also apply the ideas from the basic
control model (Hollnagel, 1998), that states that competence and context
determine the ability to control, the culture of the organisation together
with explicit norms is a substantial part of the competence of that organi-
sation, or JCS. Understanding the culture of a system is thus an important
aspect for a researcher who wants to be able to explain why a system
behaves in a certain way in a certain context. Culture and norms are also an
important part of the common ground (Clark, 1996; Clark & Brennan, 1991) in
communication (see below). This is important since it is the communication
and actions of people that forms and re-forms the norms in a system, be
implicit or explicit ones. The ability to communicate within an organisation
like the ones concerned in this thesis is to a large extent provided by the use
of information systems, and therefore it is important to understand how
people in organisations create and recreate meaning, and thus norms,
through their use of information technology (Avison & Myers, 1995). Be-
low, I elaborate on the topic of technical mediation of communication and
provide some central perspectives on tool usage.

3.6. The ability to coordinate action is
mediated through a technical
system

The important thing about an information system is not the way it is struc-
tured or the kind of technology it is made out of, the important thing is
what people do with it, namely communicating and informing. An informa-
tion system mediates actions (Vygotsky, 1978). In the introduction to the thesis,
two definitions of information systems were presented, one from Langefor-
s (1973) and one from Buckingham, Hirschheim, Land & Tully (1987). In the
context of organisations that handle crisis or war, I would like to emphasise
how information systems are used in the context presented in this thesis. In
dynamic control tasks, information systems are used primarily for monitoring, communication and coordination tasks.

One of the most important (and ironically perhaps best known!) and most often neglected issues in the design of any information system is probably the fact that what is treated by the technical components of an information system is data, but the purpose of the system is to present data in such a way that it means something to the person using the system, thus information. Information is thus data that has been interpreted by someone or something. It should also be noted that while Cognitive Systems Engineering often describe components of a system in terms of functions, it is not the same as saying that the function performed by a human “component” is the same as a function performed by a machine. Although the machine may be able to operate upon data incredibly much faster than a human, the machine never “understands” the data outside the specific context for which it has been created. Also observe that “understand” in this case simply means “respond to an event in the world in a goal-oriented fashion”. From this view, the thermostat used as an example earlier “understands” that it should increase the output from heater if the in-signal, the temperature in the environment, decreases. The thermostat would never respond to, or “understand” any other signal. A human on the other hand could interpret other cues in the environment, such as the time of day or weather, when regulating heat.

An information system thus consists of a number of technical artefacts and their users, who when using the technical artefacts share and store data that means something to them. What “meaningful” data means depends on the situation. “Meaningful” for a specific user may differ from time to time depending on both spatial and temporal position, activity, the current “role” of the person, and so on. It is also not certain that what is meaningful and needed data in one part of an organisation is meaningful and needed in another part of the same organisation. It is even common that the same data has a completely different meaning for another part of the organisation, and the data can thus be different “information” for different people. This simple fact is however often forgotten by designers of information systems:
“The fact that words have different meaning in different contexts or for different groups of people, became clear when we began to do systematic information analysis in connection with information system studies. Of course it must have been known before, among philosophers and linguists, but it was largely ignored in the data profession.”

(Langefors, 1993, pp 163)

From the discussion above, we can conclude that the everyday use of the word “information” often is misguided. Often, we tend to think of data as information, and thus ascribe a meaning to data that is not there. A more appropriate way of describing information systems would be to focus on the mediational aspect of the system, and thus regard an information system as a system that mediates communication, both direct and indirect. Braf (2004) states that “IS are designed instruments that aim to support communication between actors in organisations” (original italics). Taking a stance in socio-cultural studies, Braf points out that the design of an information system, or any artefact used in a specific activity for that matter, has a strong effect on the way that work is performed (Vygotsky, 1978; Wertsch, 1991). Below follows a discussion about what an artefact is and the role of artefacts in a JCS.

### 3.6.1 Perspectives on artefacts

A large part of the dissertation has so far been discussing the human part of the control problem, but a JCS is normally a composition of humans and technology. A term often used to describe the technology is artefact, and in the case of information systems, cognitive artefact. Langefors’s definition of an information system (above) and the original description of a cognitive artefact by Norman (1991) are not dissimilar. Norman writes that cognitive artefacts are “artificial devices designed to maintain, display, or operate upon information in order to serve a representational function” (Norman, 1991). Since the “representational function” is essential in the work of a controller, artefacts shape the way a certain task is performed. Changing the artefact will thus also change the performance of the JCS that incorporates the human using the artefact. This is an important assumption both for the positive and negative aspects of changing an artefact. Perkins (1993) refers to this as “person-plus”. A very simple example is a person taking notes on an ordinary piece of paper with a pen. The paper serves as an externalised extension of that person’s memory, allowing him to access it when the pa-
per is available to him. In almost all-everyday situations we are encountered with situations like that. Salomon, Perkins & Globerson (1991) make a distinction between effects with information-processing technologies and of information-processing technology. Effects with technology are the “amplification” of a person’s cognitive powers when using technology and effects of technology refers to the spin-off effects that occur with that technology.

Another discipline oriented towards the use of artefacts as cognitive tools is activity theory. Activity theory originates in early soviet psychology, and especially from the works of Vygotsky (1978). Vygotsky suggested that almost all human cognition is mediated through artefacts, be it physical or symbolic. These artefacts in turn are products of cultural-historical development, meaning that everything we do is a product of our culture and history, at same time as all activities possibly have effects on the artefacts used.

In this view a person uses some kind of tool/artefact to manipulate an object with the purpose of achieving some kind of goal. A very simple example would be a person using a hammer to force a nail into a piece of wood. The hammer would be the tool, the nail the object and the successful fastening of the piece of wood the outcome. Activity theory also divides an activity into at least three different levels. If we take the example above, hammering a nail into wood, it is very likely to be a sub-task of a larger activity, like building a house. Analysis in activity theory does, like analysis in distributed cognition, often produce very detailed descriptions of an activity, but unlike distributed cognition, some directions of activity theory research searches for contradictions. A well known example within the discipline is Engeström & Escalanes (1996) study of a new postal service machine, the postal buddy, which was withdrawn from service in spite of large design efforts. The authors claim that the failure depended on tool/object confusion from the view of the designers. Engeström & Escalane suggest that the developers switched from designing for the service activity that the machine was to provide, to designing the machine. The confusion caused the release of a machine that could not provide the necessary service in a useful way, but a machine that was very much appreciated by the developers (Engeström & Escalane, 1996).

The method of activity theory is, as in the case of distributed cognition, mainly ethnographic, focusing on workplace studies (Kutti, 1996). A difference although somewhat vague, is that activity theory is more focused on the historical development of an activity than analysis in distributed cognition or cognitive systems engineering. Another important analytical differ-
ence is the view of artefacts. While scientists like Simon, Norman and Hutchins see artefacts as information processors, equal to the humans using them, activity theorists see tools merely as mediating means in an activity.

Within Cognitive Systems Engineering, as described by Hollnagel & Woods (2005), artefacts and tools are analysed from the way they are used rather from what they are. In the same way as in activity theory, a tool is seen as something that is used to reach a goal. Hollnagel & Woods write:

“Since CSE uses the concept of a tool in a more restrictive way than above\(^\text{18}\), the preferred term is an artefact, defined as something made for a specific purpose. Humans sometimes use natural objects to achieve a goal, such as when a stone serves as a hammer, and sometimes use artefacts for purposes they were not made for, e.g., using a fork as a lever to open a bottle of beer…..

Although CSE does not aim to exclude any artefact the emphasis is nevertheless on those that have a certain level of complexity and functionality and which therefore typically – but not necessarily – comprise some kind of information technology. The interest is, however, not on the information technology as such but on the function and use of the artefact.”

(Hollnagel & Woods, 2005, pp 93-94)

According to the quote above, the function of a tool is not only determined in the design phase, but also in the actual use situation. The use of technologies can thus not be expected to follow the intended if the situation deviates from the norm for which the tool is designed, or if the designer has failed to understand the goals that the user has, as in the example analysed by Engeström & Escalante (1996) above. An important difference between activity theory and cognitive systems engineering concerning the view of artefacts is that while activity theory focuses on the mediational aspect of tool usage, CSE focuses on the purpose of the usage, and has less interest in the artefact in its self. The point of departure is thus fundamentally different, although the view on artefacts as parts of a system that has great impact on how something is done is shared. So far, the activity for which the artefacts are to be used for, communication, have only been described briefly. The

\(^{18}\) Hollnagel is referring to Bödker’s (1996) proposal for a division between tool, medium and system.
text now proceeds by introducing some theories concerning communication.

3.7. Communication between humans in a JCS

Language and communication is the main mean for coordinating human activities to goal-states and for the establishment of goal-states in cognitive systems (Hollnagel, 1998; Cross & Bopping, 1998; Rochlin, 2000), and thus in a sense also a tool (Vygotsky, 1978; Wertsch, 1991). Communication allows us to discuss abstract things and to co-ordinate our actions. Very early, humans used primitive signalling systems like bon-fires to warn each other and get help when danger approached. It is also communication that allows a team of individuals to act as a purposeful unit, adapting to changes in the surrounding. From a CSE perspective, communication, although somewhat absent in many texts, is extremely important:

“For each individual the general paradigm can be used to describe how control of the situation is maintained. The two “individual worlds” are, however, joined by the fact that work is carried out in a common environment, and by the communication that takes place between people. This communication may itself effectively modify the current understanding, either independent of or in addition to observations and actions”

(Hollnagel, 1998, pp 28)

Language and communication can thus be seen as a tool used by humans to mediate intentions, and ultimately, as a tool for controlling the activity of others. But communication, although a powerful tool, has certain characteristics in certain situations that need to be examined closer. Based on Clark’s notion of communication as a joint activity (1996) and basic cybernetic models of communication, the following arguments will be elaborated: that communication can only be efficient under certain conditions where it is possible to establish a common ground and where the context allows creative communication, and that, if mediated by technology, the channel and media that the communication passes through and the systems regulating that channel and media have great influence on the efficiency of that communication. These two points will together prove valuable for the understanding of spreading of intents, and thus coordination and control.
Communication becomes interesting when we look at the notion of shared understanding in a system composed of humans that are to cooperate in controlling a dynamic situation. In this field, it is not unusual that the sender of a message is a staff, a group of persons, and the receiver is a unit, also a group of people. In a proposed vision like the network-centric ones discussed in chapter two (Libicki & Johnsson, 1995), the sender can even be a technical artefact, like a sensor. In order to differentiate between transfer of data and human to human communication, the fundamentals of information theory needs to be revisited again. Shannon & Weaver (1949) divided the area of communication studies into three analytical levels, which can be seen as the basis for all information theory:

The first level concerns how exact something can be transmitted. If it concerns alphabetical or numerical symbols, the simple question is; will the symbol the sender produces look the same when it reaches the receiver, or is there some kind of loss or distortion that makes it difficult to interpret?

The second level concerns the semantics, how well the symbols represent the intended meaning.

The third level asks the question of efficiency. If a message is intended to affect the receiver in some way, how well did it succeed?

The first level is mostly of technical interest, and has already been mentioned above. The second two levels will be discussed below. After all, from a CSE perspective, the primary interest is in the purpose of communication (what the controller wants to achieve) and thus what the pre-requisites for communication are.

### 3.7.1 Pre-requisites for efficient communication – dimensions of communication and control

Linguists and psychologists like Clark (1996) or Heath & Hindmarsh (2000) have observed that meaning, level two according to Shannon & Weaver, often is negotiated or constructed jointly. Further, Clark emphasises that the use of language should be viewed from an action approach. Most actions that humans perform together with someone else are joint actions, and such actions are normally enabled by using language (Clark, 1996). Joint activities exist in many forms, but they have to be goal oriented. According to Clark, there can be an almost infinite number of different activities, but he exem-
plifies with dichotomies like scripted vs. unscripted activities, i.e. a marriage ceremony versus a chance meeting, or a verbal vs. a non-verbal activity. Naturally, an activity can belong to more than one dimension. Scripted activities like a marriage ceremony has a clear goal and procedure, while in other, less formal activities, emerge over time where two or more participants try to reach certain ends.

A basic unit of communication, or a pre-requisite for communication, in Clark’s view is common ground. Common ground is the smallest shared understanding of the activity that the participants need to have in order to engage in a joint action with a higher goal than creating common ground. Common ground can be divided into two broad types, communal common ground, composed of attributes like cultural background, nationality, gender, age, professional knowledge etc, and personal common ground. The latter is based on personal acquaintance; it is lacking in strangers and greatest for intimates. Personal common ground is based on joint perceptual activities and joint actions. Establishing this between two participants with very different communal common ground will be time consuming and effort demanding.

A simple example of common ground is person A throwing a ball to person B. Unless person A’s intent is to throw the ball to person B, and Person B’s intent is to catch it, we cannot call the action joint. The common ground in this case is the shared understanding of the activity (catch-throw), and the joint activity emerges from the intent of fulfilling these obligations. The essential components of common ground are three:

Initial Common Ground. The background knowledge, the assumptions and beliefs that the participants presupposed when they entered the joint activity.

Current state of the joint activity. This is what the participants presuppose to be the state of the activity at the moment.

Public events so far. These are the events that the participants presuppose have occurred in public leading up to the current state.

(Clark, 1996, pp 43)

The common ground in a joint activity is from the perspective of the basic cyclical model (see above), parts the constructs that the persons engaged in the activity have. The maintaining of common ground is thus an ongoing process, which demands both attention and co-ordination between the par-
Participants. The second component, the current state of the joint activity depends both on the participants’ initial common ground and on the public events so far. It is easy to see the connection between control work and communication. Exercising command and control is, according to McCann & Pigeau (McCann & Pigeau, 2000; Pigeau & McCann, 2002) an attempt to establish common intent to achieve co-ordinated action. Successful communication is necessary to achieve this.

“Sharing explicit intent efficiently requires that at least three conditions be met: (a) a common language must exist; (b) the parties who are attempting to communicate must have a baseline level of literacy in that language; and (c) a communication medium must be available. Deficiencies in one or more of these conditions will hamper the sharing of explicit intent.”

(McCann & Pigeau, 2000, pp 168).

As can be seen, McCann & Pigeau does not use the notion of common ground, although they emphasise that there is a large set of underlying assumptions that is refereed to by persons in a command and control situation. McCann & Pigeau differentiates between what they call explicit intent and implicit intent. Explicit intent is the articulated and formalised intent, like an order. A message sent from person A to B is thus explicit. Implicit intent is the shared understanding of how to act in a certain situation, or the ability to imagine what another person would want you to do.

“We maintain that sharing implicit intent is at least as much about unconsciously learning subjective norms and developing normative beliefs as about consciously seeking opinions and achieving consensus…….

Mess dinners, unit functions, religious gatherings, operational exercises, informal briefings, casual conversations – all are venues for sharing (that is, implicitly learning) the subtle expectations and beliefs that will become the foundations for operationally relevant shared implicit intent.”

(McCann & Pigeau, 2000, pp 170).

McCann & Pigeau suggest, in line with the ideas presented from Schein (see above), that the way we act and interact to a large extent is shaped by the implicit intent, the norms and rules that we live by that not are outspoken. Both in our private and professional life, we carry a number of expectations with us that are relevant. Such norms may change over time, but traditional settings, like the ones mentioned above (mess dinners, religious ceremonies)
also preserve the norms that we live by, and also our understanding of the world and other actors in it. Lave & Wenger (1993) makes a similar observation when they describe the mutual constitution of practice and learning.

In a healthy organization, redundant communication with the purpose of maintaining and enforcing roles and norms often occurs.

“In work by the HRO group on aircraft carrier flight operations, a constant stream of traffic was found to take place simultaneously over multiple communication links during flight operations, even when the level of operational activity was low (Rochlin et al. 1987). By comparing it with other similar, if less dramatic, activities taking place elsewhere on the ship during critical operations, it was found that the constant chatter was an important means for maintaining the integration of the collectivity and reassuring all participants of its status. ……

The ‘social organizational safety’ described by Janssens et al. (1989: 124) depends on the ‘spontaneous and continuous exchange of information relevant to normal functioning of the system in the team, in the social organization’. Such inter-communication was therefore identified as a primary goal of safety training programs for operators.”

(Rochlin, 1999, pp 1553-1554)

The communication of the personnel in the example above became a primary component in upholding the basic regulating task of the JCS. According to Hollnagel’s basic cyclical model (figure 2) above, the construct, which is the basis of the feedforward in the system, is to a large extent based on feedback. When little actual variation in the control task occurs, and communication/interaction no longer really is necessary, the basis for establishing a sound construct becomes vaguer, and uncertainty arises. Therefore the personnel creates own feedback by a constant exchange of information, just to assure that everything is working all right, but also to re-enforce their roles and relations to each other. This is also related to Weinbergs & Weinberg’s “fundamental regulator paradox” (1988). The regulator paradox states that the variation in the feedback from a system that works as it should is low, and consequently, the less information the controller will get on how to improve. It is also so that the need for feedback is related to the redundancy in the system. If it is possible to misinterpret a message or intention, the redundancy decreases, and the need for feedback increases (Fiske, 1990). By constantly interacting in the way described in the quote
from Rochlin above, the common ground is maintained, and the focus of the communication can be held on the activity at hand.

### 3.7.2 Communicating through channels and media

Another important factor influencing communication and coordination is the design and structure of the communication system. During the last decade, the possibility to transfer large amounts of data has practically exploded. Modern information systems allow us to communicate practically with anyone in the western world through several different media/modalities by just pushing a few buttons. It has however been known for a long time that the channel and media used for communication have great influence on how we can communicate. Different mediums for communication have different effects on the outcome of communication, and thus control (Shannon & Weaver, 1949; Gerbner, 1956; McLuhan, 1964). The constraints put on communication by various media and channels are thus important. Mediums and channels are often described in terms of whether the communication is direct (synchronous) or indirect (asynchronous) and the relation between the sender and the receiver(s). The table below (Table 2) shows a basic categorization of some common media in two dimensions.

**Table 2. Dimensions of communication.**

<table>
<thead>
<tr>
<th></th>
<th>One-way (1:N)</th>
<th>Many-to-many (N:N)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Communication</strong></td>
<td>Television, Broadcast radio, Face-to-face, telephony, radio, chatt, etc.</td>
<td>Newspapers, books, home-Post, e-mail, homing pigeons, pages, etc.</td>
</tr>
<tr>
<td><strong>Synchronous</strong></td>
<td>(direct) communication</td>
<td>(indirect) communication</td>
</tr>
</tbody>
</table>

Most information systems used by organizations today have the capability of many-to-many communication, and often both in the form of synchronous and asynchronous communication. It is naturally so that a system that has the capability of many-to-many communication can be used as a one-
way tool, both from a technical perspective, but also from an organizational/social perspective. If, for example, the manager of a large company sends out new directives via e-mail, the norm, the “social law” makes it unlikely that anyone will reply with objections to such a mail, at least directly. The dilemma of one-way communication is the lack of feedback. While many-to-many communication allows feedback, and thus adaptation, one-way communication increases the demand on the sender since he/she/it should be able to produce a message that is understandable by the recipient without any further explanation. The dimensions presented in Table 2 are especially important in information systems because such systems often have all of the dimensions. A message stored in a database is not only asynchronous, it may also be either one-way or many-to-many depending on the configuration of the system and the way the creator of the message has chosen to store it. The duration between the creation of the message and the occasion when someone actually reads it may also be uncertain, as well as the spatial distance between the geographical position where it was created and the one where it later was interpreted. A simple example is a web page on the Internet. Such a page may be created almost anywhere in the world, and its contents may be several years old, meaning that it is very hard to tell how a reader of the page will interpret it. The need for cues that contextualize a message is thus a very important part of an information system. The dimensions of communication is however only one of the things that determine how well it is possible to communicate. The medium is equally important. If we look at various media, we find that they put different kinds of constraints on their users. For example, a video connection between two persons allows more feedback in the communication, and thus more redundancy, than for example written communication in a chatt. Researchers like Herring (1996), Svenningsson (2001) and Hård af Segerstad (2002) have shown that experienced users of text-based communication like chatt enforce their ability to express for example feelings (happiness) or layers of communication, like irony, by using combinations of signs, like “smiley’s”, abbreviations etc. This suggests that written communication limits the way people can express themselves compared to verbal or face-to-face communication, creating a need for an extension of normal written language. Gerbner (1956) showed the effects of channels and media in his extension of Shannon & Weavers (1949) basic model of communication (see figure 5).
Figure 5. Gerbner's model of communication (1956).

According to this model, something (a perceptive event, E) is perceived. This can be an object or an event of some kind. This is perceived by someone or something, a person or a machine, who interprets the perceived according to the possibilities given by the circumstances, creating the imagery, E1. M then produces an utterance or some other kind of message, H, which is delivered to M2, the receiver. However, the message/utterance has to pass through the channel, S. This channel can be anything from face-to-face communication to a very bad radio/phone line or a painting. It is the form of H, and H is the content. This two are inseparable (Fiske, 1997). M2 then must perceive and interpret SH, just like M interpreted the original E, and creates his/her version of SH, SH1. A fundamental point made in this model is that everything that is communicated is a selection of possible interpretations, forced through some kind of mediating channel and then reinterpreted, meaning that it is more or less impossible to assure that what M perceives may not at all be what M2 interprets from SH. Another crucial point made is that the selected information-channel (S) has great impact on the possible interpretation, meaning that the most crucial point for M is to find the adequate channel to distribute his content, H, with.
Chapter 3. Theoretical background – Control, tools and communication

Today, many information systems use text as the basic form for communication in various media, such as e-mail, chat or recipe-based machines like fax. This means that information systems offer people different means for communication than to older systems (Artman & Waern, 1998; Johansson, Artman & Waern, 2001) where verbal communication was the core mean for exchanging messages. Modern information systems often tend to favour text-based communication instead of verbal communication in order to make communication traceable and storable (Johansson & Persson, 2002). This can be done both by enforcing user to mediate communication via text-based systems (e-mail) or to communicate according to sequential patterns in order to utilize databases (Artman & Waern, 1998). An important aspect of these findings is that although advanced communication systems helps us to structure the communication, and thus helps the controlling system to perform in a regular way, it also limits the way human actors in the system can express themselves. Artman & Waern’s analysis of an emergency coordination centre shows how the personnel who answer calls from the public are forced by the information system they are using to collect data from the (often frightened and stressed) people in need that calls them (1998; see also Johansson, Artman & Waern, 2001). Johansson & Persson’s study (2002) show how users of a large military information system is forced to work around the information system during phases of intensive work, since it simply is to slow to communicate in a text-based medium in comparison to the task at hand. The relation between the rate of change in the control task was simply to high to handle with anything less than voice communication, because even small delay in feedback could be disastrous.

To summarise this section, we need to remember that there are a number of things that have impact on how effective human-human communication is, and thus how well a JCS can change its behaviour in relation to the environment. The factors that affect human-human communication are how well established the relation is between the participants in the communication (social network, common ground), the context (physical setting and situation) and the technical infrastructure (channels and media). This chapter has given a theoretical background for chapters four and five. In the next chapter, the four papers included in the thesis are presented. They all share the fact that they have studied humans working in groups with the purpose of controlling a dynamic situation, and that technical communication tools were used to a large extent in their work.
4. Summary of studies

Four papers are included in this thesis. The first two papers presented here are based on a microworld study. The third paper uses data from three different studies, partly data from an earlier study by Artman (Artman & Waern, 1999), another study by Artman & Persson (2000) and parts of the video analysis from the ROLF-study presented in paper one and two. The fourth paper is based on an analysis of eleven transcribed interviews gathered by P-A Persson in 1994-1995 (Persson, 1997).

**Paper 1**, *Feedback in Shared Digital Maps*, reports the findings from a study examining the effects of direct or manual updating of a shared representation in a team decision making task. The representation was central source of information to a team of decision makers solving a dynamic control task.

**Paper 2**, *C3Fire in Command and Control Research*, concerns the use of microworlds to investigate the effects of new technology in command and control work. The paper discusses the method of microworld studies in relation to the study described in paper 1.

**Paper 3**, *Technology in crisis management systems – Ideas and effects*, concerns the effects of new technology on emergency management and military command and control work. Examples from field studies, exercises and experiments are provided.

**Paper 4**, *Communication as Control – Human communication in complex systems*, concerns communication and control in a complex situation. Eleven com-
manders from the first Nordic battalions that took part in the UN-efforts in former Yugoslavia were interviewed. The analysis of their accounts is discussed in relation to how communication between humans is treated in cognitive systems theories.

Below follows a summary of all four papers. Each paper is divided into five sections; Purpose (of the paper, i.e. to report finding, discuss method etc), Method (how the study was performed, what kind of data that was gathered and how it was analysed), Conclusion (what were the major conclusions of the paper), Discussion of the paper (how do I view the paper in retrospect, could something have been done differently etc), and Contributions (what were the contributions of the paper). The ambition is not to provide a complete re-written version of the papers and their contents. The reader is therefore encouraged to look to the complete papers, which are included in the thesis, when wondering about details. The same concern references to theories. An overview of the theories used in this work is available in chapter three. A discussion of the findings in the papers in relation to the questions raised in 2.5 and the theoretical background can be found in chapter 5.

Since the usage of micro-world simulations, specifically the C3Fire microworld, has been central in paper 1 & 2, and partly in paper 3, I have chosen to provide some background to microworlds and C3Fire below.

4.1. Microworlds

Microworlds have been used in research on decision making since the late 1970ies (Funke, 1992; 2001), and was originally used because of the complexity and dynamics that were offered by computer simulation in research on decision making. Brehmer & Dörner (1993) suggests that microworlds bridge the gap between the traditional (psychological) laboratory study and the “deep blue sea” of field research. A microworld could be seen as a computer-based simulation. This is partly true if we by simulation mean any computer program that has some similarity with a real-world task. That would however be a misuse of the term, since a simulation often claims to be a more or less exact representation of a real-world task. For example, a flight simulator for professional training may be very advanced, providing an almost entirely realistic interaction. This is not the purpose of a microworld.
“In experiments with microworlds, subjects are required to interact with and control computer simulations of systems such as forest fires, companies, or developing countries for some period of time. Microworlds are not designed to be high fidelity simulations. Instead, they are related to the systems that they represent in the same manner as wood cuts are related to what they represent. That is, it is possible to recognise what is being represented, but there is little detail. However, microworlds always have the fundamental characteristics of decision problems of interest, here, viz., complexity and in-transparency.”

(Brehmer, 2000, pp 7-8.)

The purpose of a micro-world is thus to present a recognizable problem to the subjects using it. But the microworld must still be complex enough so that the subjects experience a dynamic situation with uncertainty. A recognizable task can typically be forest fire fighting (Brehmer & Allard, 1985; 1991; Svenmarck & Brehmer, 1994; Granlund, 2002; Gray, 2002; Schiflett, Elliot, Salas & Coovert, 2004). The important point is not to preserve detailed real-world characteristics, but rather to have a level of fidelity that is high enough to be acceptable by the participants in the study but yet low enough to be easily manageable and analyzable by the researcher(s). Microworlds are characterised by the fact that they are complex, dynamic and opaque. They are complex because the subjects have to consider a number of aspects, like different courses of actions or contradicting goals. Secondly, they are dynamic in the sense that subjects have to consider different time-scales and unforeseen effects since the relationship between different variables are uncertain. The opaqueness comes from that some parts of the simulation are invisible to the subject, who has to view the target system as a black box. They thus have to make hypotheses and test them in order to handle the situation (Brehmer & Dörner, 1993). These three characteristics are representative to many real world situations, and definitely to the situations that new information systems for crisis management are meant to be used in. Therefore, it could be assumed that microworlds are suitable not only for investigating how people behave when they are confronted with a dynamic problem, but also for investigating the effect of new technology in relation to the ability to handle such tasks.
4.2. C3fire

The study presented in paper 1 and 2 (and partly in paper 3) was performed using the C3Fire microworld (see figure 6). As pointed out by Brehmer (2004), it is advantageous to keep on conducting experiments with microworlds that have been used previously so the research community gathers comparable data. Also, well-documented experience about the use of this microworld exists, something that helps other researchers that wish to compare the studies in this thesis with other research. C3Fire (Command, Control and Communication) is a micro-world based on the forest fire-extinguishing task, originating from the DESSY (Dynamic Environment Simulation System) (Brehmer, 1987), NewFire (Lövborg & Brehmer, 1991) and D3fire (Distributed Dynamic Decision Making) (Svenmarck & Brehmer, 1994) micro-worlds (Granlund, 2002)\textsuperscript{10}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{C3fire_diagram.png}
\caption{The C3fire micro-world. The subjects have to cooperate to extinguish a simulated forest-fire. The development of the simulation is set by a manager in a number of script-files (Granlund, Johansson & Persson, 2001).}
\end{figure}

\textsuperscript{10} Another important microworld in the fire-series is FireChief, developed in Australia, see Omodei et al (2004).
The problem presented in the C3fire microworld is that a number of fire fighting units have to be coordinated in order to extinguish one or more forest fires. The simulation may contain other objects than forests, like houses. C3fire can be configured for many different purposes, but typically it is arranged in such a way that a staff is responsible for coordinating two or more ground-Chiefs (humans) that in turn control fire fighting units (simulated). The basic structure of the system can be seen in figure 6.

The C3fire microworld is distributed in a client-server configuration, meaning that each subject working in the simulation runs his own client. The experiment administrator have the power to decide which participants that can communicate with each other, and also how much data all participants are to get from their fire brigades concerning positions on the map and how much the brigades actually see of the map (see figure 7).

![Figure 7. The C3fire client interface. Each fire brigade is represented by a number.](image)
It is also possible to share databases in the microworld, for example textual and graphical (Artman & Granlund, 1999; Granlund, 2002). Each trial is based on one scenario file and one configuration file. The scenario file contains information about where a fire is to start and when, how fast the wind blows, in which direction, how long a simulation should last and messages that are to be sent from the simulation to the participants. For example, it is possible to send a message with an alarm about a new fire to one or more of the participants at any given time. The configuration file contains information about objects that exist in the simulation (trees, houses, fire brigades), which roles that are available and which information they are to receive from the simulation respectively.

All events in C3fire are saved into a log-file. All interaction in the system can be measured, like positions of fire-fighting units, fires, messages sent, burned down area etc. What typically is measured as performance criteria is the area that has burnt down/being saved.

### 4.3. Paper 1: Feedback in shared digital maps

Written together with Rego Granlund, paper 1 is based on the results from a study conducted 2000-2001 at the Swedish National Defence College. The paper was published as a conference proceeding at the European Annual Manual (EAM) conference on Human Decision Making and Manual Control in Örsted, Denmark, 2001.

#### 4.3.1 Purpose

The purpose of the paper was to examine the effect of different ways of updating shared representations used as an information source in team decision making. A combined method with both quantitative measures as well as qualitative analysis of video was used. A comparative study was designed where two conditions were examined. Direct updating, where members of the rescue organization “on the field” could input data directly on a shared representation, was compared with manual updating. In manual updating, the commanders in the staff had to update the representation themselves, based on e-mails from “the field”. These two conditions were compared in a series of trials.
4.3.2 Method

At the time of the study, a large project had been initiated at the Swedish National Defence College called ROLF 2010\textsuperscript{20}. The purpose of that project was to create a command environment (a staff room), where teams of decision makers could work jointly around a large table-like screen, promoting a shared view as well as an environment that enabled discussion and creativity to a larger extent than at traditional staff environment (Sundin & Friman, 1998), and thus also increase the quality of decisions made. It was essentially this idea that the study aimed at studying. A prototypical environment was built at the National Defence College, where such a table-like screen, and additional computers and screens, were available for experimentation (see figure 8 for an artist’s impression of the environment).

![Figure 8. An artist's impression of the future command and control environment. A staff gathers around the table-like screen.](image)

In the paper it is argued that there are basically two ways to deal with the updating of the shared representation. One possibility is to provide input from the “outside” (sensors etc) directly on the shared representation, updating directly. The other way is to provide the staff with “information” (messages etc) and let them update the shared representation themselves.

In order to investigate the possible pros and cons of the two possibilities, a microworld called C3Fire (Granlund, 2002) was used (see above). The microworld was configured in such a way that a team of commanders (four

\textsuperscript{20} Rörlig Operativ LedningsFunktion (Joint Mobile Command and Control Project).
persons) were to coordinate the efforts of two subordinates that in turn controlled four fire fighting units in the microworld, hence creating a mini hierarchy. Two conditions were used, one where the commanders received unit positions and development of the forest fire directly. This information was provided by the ground-chiefs who updated a map database. Any update was immediately presented on the shared screen in the command centre. In the other condition, they had to communicate via e-mail with their subordinates in order to get such data (see figure 9).

![Diagram](image)

**Figure 9.** The design. Two conditions were used, one where the shared representation in the staff room was updated directly from the “field” and one where the staff received messages from the “field” containing data about unit positions etc. and had to update the shared representation “manually”. The staff room was video-recorded from two different angles.

The design was a 2 (direct updating/manual updating) X 3 (trials) design with repeated measures of the latter factor. Each session consisted of one training trial and three trials. Each participant was randomly assigned to a role in the study. The following roles were available, commander, assistant commander, communications officer and ground chief. All trials were identical, apart from the fact that the map was rotated. The participants were not informed about this.
Army officers were used as participants. All of them had the rank of at least lieutenant. The paper reported findings from eight out of a total of ten planned experiments. All participants were randomly assigned to the conditions.

The data that was collected was the log-files from the C3Fire microworld (see above) and video recordings of the work in the staff. Two video-cameras and several microphones were used to capture the interaction in the command centre.

### 4.3.3 Results/Conclusions

The quantitative data from the study could not point to any clear differences in terms of saved area in the simulation. According to the expectations in the original vision, it would have been expected that the direct condition would have performed better (Sundin & Friman, 1998). The variance was actually higher in the last trial in the direct-update condition (see figure 10).

![Graph showing percentage of area burned down by trial](image)

*Figure 10. Burned down area in the experiment. Please observe that a low score is better than a high score since the measured value is burned down area in the simulation.*

All teams but one improve their performance over the three trials in the text-condition while half of the teams in direct-update decrease in performance in the last trial. The difference in precision of the information (data) presented on the shared screen was also examined. It was observed that in
the last trial, all teams in direct updated received more information (more frequent updates on the screen) as well as more precise (positions matched “reality” to larger extent, and the average error between actual and presented positions were much lower). So, although the data presented on the shared screen was less accurate in the manual updating condition, it did not deteriorate their performance in comparison to the direct update condition.

The qualitative analysis of the video-recordings revealed that the work conditions in the two conditions differed. In the manual update condition, the division of work was clearer. It was hypothesised that the military commanders in the manual updating condition took advantage of the similarities in working with traditional paper based maps. In direct update, the command team rather gathered around the shared representation, waiting for something to happen. It was suggested that this might hamper performance in the direct-updating condition since the tool eliminated the need to constantly monitor the e-mails coming from the ground-chiefs, but it also forced them to look at the shared screen. In manual update the commander and the assistant completed the picture based on verbal reports from the two communications officers. These verbal reports were spoken out in the room, meaning that anyone in the room also could hear what was going on. This can possibly have minimized the need to observe the shared screen for assessing the situation. There is also a risk that the direct updating condition, with its higher rate of data input on the screen, creates a situation where the commanders are “chasing” the situation rather than handling it.

4.3.4 Discussion of paper 1

The qualitative analysis in the study showed that there were differences in the working process in the two conditions. An aspect that was missed in the study was how non-military participants would have behaved. It was hypothesized in the paper that the condition where the participants base their understanding of the situation from e-mails was more similar to their “normal” working condition. If that would be true, the results might have been different. This was however not tested. In a forthcoming study (the design is presented in Trnka, Johansson & Granlund, 2005), a similar study is suggested, but with student participants. That study will perhaps answer if participants not working with command and control on an everyday basis performs differently than the participants in paper 1.
It can also be concluded that it probably would have been more appropriate if the updating of the shared map would have been performed automatically. In the study, the ground-chiefs had to perform this task. Although it seems as if it worked well, it introduces some uncertainty since the ground-chiefs also are to perform the task of fighting the fire. With automatic updating (which in reality easily can be done with for example GPS), there would have been no differences in terms of accuracy in the presented data on the shared screen between the teams in direct updating. As can be seen in the paper, the actual difference in accuracy between the teams using direct updating was very small, but the control would have been higher with full automation.

4.3.5 Contribution of paper 1

Paper 1 did not provide any answer to the question about performance in relation to direct updating of shared representations is better or worse than manual updating of such representations when a team faces a dynamic control task. In the results presented, the perhaps most interesting observation was that no support was give to the idea that access to fast and accurate data increases performance. There were clear qualitative differences between the conditions in terms of the work procedure. The study generated some hypotheses suggesting that direct updating was not superior to manual updating due to the contradiction between the traditional work-procedures of military personnel and new technologies.

4.4. Paper 2: C3Fire in Command and
Control Research

Written together with Mats Persson, Rego Granlund and Peter Mattsson, paper 2 uses the study in paper 1 as a point of departure for discussing the role of microworlds in command and control research. The paper was originally written as a conference paper for the conference “Cognitive Research with Microworlds”, in Granada, Spain, 2001 (Granlund, Johansson, Persson, Artman & Mattson, 2001). After revision, the paper was included in a special issue of the international journal Cognition, Technology & Work about research with microworlds, published in 2003.
4.4.1 Purpose

The purpose of the paper was to present experiences of how microworlds can be used to investigate new technical or work organisational solutions in command and control situations. An earlier study, which in this case was the one reported in paper 1, was used as an example.

4.4.2 Method

Since the paper was based on the same study as paper 1, the design and conduct of the study were in accordance with the above description. When this paper was written, all the data (10 teams, 5 in each condition) had been gathered. An additional analysis of the communication within the teams was performed.

4.4.3 Results/Conclusion

The study reported in the paper provided some interesting observations. It was discussed, based on the study presented in paper 1, that the method of using microworlds to investigate new technology in experiments was possible. Especially, microworlds as a tool for investigating “visionary” technologies and organizational ideas was emphasised. Concerning methodology, team experimentation was described as a special form of studies. In many occasions, the dynamics that were observed in the simulation seemed to originate from the simple fact that several people tried to cooperate, with all the problems and frictions associated with that. The paper concluded that “Simply involving a large number of persons under stress seemed to reflect more real-world problems than the fidelity of the simulation” (Johansson et al, 2003, pp 195). The importance of participant acceptance when working with simulated environments was also pointed out. During the experiment, most participants reported that they considered the experiments to be meaningful. The participants also quickly adapted to the situation and used their professional (military) language (terminology, way of expressing themselves), indicating that they saw a connection to their ordinary work-situation.

Another interesting finding was that by not only using the military officers as experimental subjects, but also putting them in the role of observing each
other when performing an experiment, the researcher can gain access to their “professional vision” (Goodwin, 1994). This might help the researcher to derive new theories or measures. It was shown in the study that by getting access to the participants’ specific way of expressing themselves, it was possible to create a software tool that could analyze the communication between the participants and categorize it automatically. The tool made it possible to identify changes in command style and study it in relation to performance and other measures. This was exemplified in the paper. To study process as well as outcome is thus an important aspect of research on new technology since it is important to understand both the impact on performance as well as the effects on work procedure.

4.4.4 Discussion of paper 2

Although presenting a reflection on some important aspects of microworld research, parts of the paper needs to be commented. The paper did not only discuss the contents presented earlier in the paper, but also brought up some new observations. Although it is common to elaborate on methodological issues in a discussion, some evidence for the statement that the participant acceptance of the microworld was high should have been provided. Neither are any accounts of the use of professional, domain specific, language given, although we mention this as an evidence for that the microworld “reflects some crucial aspects of teamwork in dynamic settings”. That statement was based on observations made during the experiments, and comments from the participants.

In the paper, the participants were referred to as “professionals”. This is inappropriate since their professional background is not directly related to the problem presented in C3Fire. Military officers are experts at commanding and solving dynamic tasks, but they are not experts at fighting forest fires. This means two things: Firstly, the term “professionals” should not have been used. Instead, it would have been more appropriate to state their exact background and referred to them as “Military personnel”, or a similar.

The use of peer observation in the study was promising as a way of generating hypothesis and identifying aspects of the activity that a non-domain expert may fail to see. McNeese (2004) suggest a similar approach where microworlds are to be used to investigate effects of new technology on teams, where process as well as outcome should be studied. However, he does not explicitly emphasizes the importance of using professional partici-
pants in the study, and the McNeese paper mainly focus on the usage of video analysis in combination with microworlds as a method in CSE.

4.4.3 Contribution of paper 2

The paper contributed to methodology in command and control research by showing how a microworld can be used to examine the effects that a technical artefact has on both performance as well as procedure in a dynamic control task. This means that microworlds can be used not only for investigating the traditional microworld focus, dynamic decision making. The concept of using observers with a similar background as the participants in microworld studies in order to generate hypothesis or new tools for analysis is also promising. This concept deserves further attention.

4.5. Paper 3: Technology in crisis management systems – Ideas and effects

Written together with Henrik Artman and Yvonne Waern, paper 3 originates from a panel discussion held at the IPRA (International Pragmatics Association) conference in Budapest, July, 2000. The panel contribution was re-written into a paper and submitted to a special issue on pragmatics in crisis, published in the journal Document Design, a journal focusing on “research and problem solving in organizational communication”. The paper was published in 2001. Parts of the data material have earlier been reported in Artman & Waern (1999) and Artman & Persson (2000). One example is taken from the qualitative analysis of the shared representations material presented in paper 1 & 2.

4.5.1 Purpose

The overall purpose of the paper was to point out the contradictions between actual work practice and the trends in system design for crisis management. Based on observations of actual work, exercises, and experimental simulations, three dichotomies were pointed out: Commitment vs Information storage, Silence vs Trans-
parenthood, and finally, Mimetic representations vs Interpretation of representations. The examples were gathered from systems in emergency centres as well as military command and control training facilities.

### 4.5.2 Method

The study was qualitative, although the excerpts were gathered from several different settings, ranging from experimental studies to actual work situations. One part of the presented material was gathered from an emergency call centre. Fifteen different episodes of caller-receiver interactions were examined\(^{21}\). The second part of the material consisted of a total of fifteen hours of video material gathered at a military exercise\(^{22}\) and in one experiment. The examples used were chosen from earlier studies in order to illustrate phenomena that not had been reported in those studies.

### 4.5.3 Results/Conclusions

Firstly, the paper reveals that operators in an emergency call centre had developed communicative practices that made it possible to cope both with the handling of callers and the technical systems they had at hand. By listening to other operator’s communication with the callers, the operators were able to act in a coordinated fashion and aid each other without explicit requests for help. The phenomenon of “talking to the room” was common in the studied emergency centre, although much of the technical equipment was intended to be used silently. Our conclusion was that there exists a trade-off between individual work, which mostly is performed silent, and cooperative work, where people have to support each other. This trade-off needs to be taken into account when designing systems for team work.

Secondly, technologies like GPS, satellite images and video surveillance, just to mention a few, make it possible to represent a situation with very precisely. From a technological/rationalistic perspective, it is argued that a faster and more precise representation generally is better than a slower and

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\(^{21}\) Also reported in Artman & Waern (1999).

\(^{22}\) Also reported in Artman & Persson (2000).
less precise, since it provides a decision maker with accurate information. Therefore, operators in a decision-making situation should be provided with as fast and accurate information as possible about the environment and processes that they work with. In the paper, that perspective was challenged. The conclusion was that operators need representations that are based on their knowledge and needs rather than mimetic representations. Situation assessment, expression of intentions, hypothesis generation and decision making might not be supported in the most efficient way by very exact and finely granulated representations.

Perhaps, the most important conclusion of the examples given in the paper was that the demands in actual practice in crisis management often derive from the assumptions of the designers of the system. This was especially clear in the emergency call centre examples, where the system supports the actions of storing information, but not the actions that are considered important by someone calling the centre, committing to action and communication. The concluding remark was that the intricate practices developed by operators may easily be disturbed by technical systems that are too complicated.

4.5.4 Discussion of paper 3

In the two first papers, microworlds were used to examine the effects of technology on crisis management, but it is also important to study actual work with information systems in real-world situations. The mimetic representations that we presented were, at least at the time when the paper was written, not that common, and we had not encountered them in technologies that actually were used in crisis management. They did however, as can be seen in the paper, exist in prototypical settings. Therefore, one example from an exercise in the prototype command and control centre at the Defence College was used, as well as from an experiment from the same setting. At the time, this setting was one of the most advanced of its kind, and could therefore serve as a representative of future technology. This could have been emphasised in the paper, although it was indicated.

From a more general perspective, the paper could have been more elaborated in the Discussion/Conclusion chapter. In retrospect, it would have been appropriate to discuss the role of technology in a more balanced fashion. Technology is after all not only a burden or constraint, it may also be an enabler. For example, it was never discussed what the situations analysed
might have looked like \textit{without} the technical devices, and what kind of strategies the operators could have used to counter the lack of technical support. It was also, probably rightly, argued that the design of the systems that were analysed only were based on assumptions from the designers. It is however not certain that this is the case, and therefore the statement should be seen as a general comment rather than a direct comment on the cases.

\subsection*{4.5.5 Contribution of paper 3}

Paper 3 contributes by giving empirical examples of how operators adopt to circumstances created by technology rather than their main task. To establish a practice that is adapted to the technical system may nevertheless also give some practical guidelines about how to design a system. In the case of the three dichotomies presented, the actual work practice was adapted to meet the demands of technology and the situation, rather than just the situation. The main objective for design of systems for emergency or crisis management must be to find designs that support the activities of the operators rather than taking focus away from them.

\section*{4.6. Paper 4 Communication as Control – Human Communication in Complex Systems}

Written together with Per-Arne Persson, paper 4 is based on interview material from the early peace-keeping operations in former Yugoslavia. The material was gathered in 1993-1994 reported in (Persson, 1995, 1996, 1997). In those cases, the material was used for a different purpose. The gathered material consisted of eleven interviews with commanders that worked in two Nordic battalions that participated in the UN-lead peace keeping operation. The interviews were recorded on tape and transcribed. These transcriptions have served as the basis for the analysis in the paper.

The paper has been submitted to the international journal Cognition, Technology & Work.
4.6.1 Purpose

Three important issues were put forward in the paper; 1) the importance of social relations and common ground in joint activities, 2) the relativity of efficient human-human communication, and 3) the risks of technically mediated communication.

To illustrate this, a case from a UN peace keeping operation was used. The authors use this case to discuss how terms like “communication” and “engineering” (especially cognitive engineering) is used, and what the possible problems of this can be. Although it is possible to achieve coordination by for example pre-made plans or constraint management, most systems that act in the world will sooner or later need to exchange information between its parts in order to attune their behaviour/directions so that they perform in a coordinated fashion. It was argued that communication is an almost unavoidable activity in any system that needs to coordinate its components. In practice, systems or an organisation that perform in the world spend a great deal of time communicating.

The paper focused on systems where humans play a central part, as they do in most everyday systems. A theoretical background was presented, where it was concluded (based on the presented theories) that the following demands must be fulfilled by anyone that wants to communicate efficiently with others in a socio-technical system:

- A channel with sender, communication medium and receiver.
- A language that all participants in the activity can understand.
- An understanding of the being/machine that is to be controlled and the context in which it acts so that the message can be formulated in such a way that it makes sense to the receiver.
- A motivation/rationale for what the sender wants to communicate.

4.6.2 Method

As described above, the paper is based on material gathered in 1993-1994, after the peace keeping mission in former Yugoslavia was initiated. Eleven interviews were made with commanders on different levels from two Nordic battalions participating in the operation. These interviews focused on four main areas; Command and Control Work, Cultural differences and
Operational aspects, Information flows, and Training and preparations. The interviews were open-ended. All interviews were recorded on and transcribed. The method of interviewing was chosen because it was impossible (at the time) to participate and make observations in place. The transcriptions have been analysed thoroughly by both authors. They were broken down into categories related to issues of communication and information technology, in accordance with mainly open and axial coding within a qualitative analysis (see for example Strauss & Corbin, 1990). The analysis does however start with a theoretical understanding (see above), aspiring to synthesize the analysis in an elaborated understanding of communicative actions and processes.

**4.6.3 Results/Conclusion**

A total of fifteen excerpts, followed by analysis and discussion, were presented in the paper. The results were divided into two overarching categories; Grounding – The importance of having and establishing relations, and The experience of mediated communication. Within these categories, a number of examples were provided.

The first category, Grounding – The importance of having and establishing relations, presented excerpts where informants declare that they considered it important to know the person that they communicated with, especially when it concerned mediated communication. The need for having relations to individuals in other parts of the organisation that one often came into contact with was pointed out as a very important issue. The analysis points out that the establishment of relations not only is important when it concerns the own organisation, it may be even more important when it concerns interaction with the surrounding world. In the case of a peace keeping operation, UN personnel constantly interact with other parties that have their own agendas. To establish working communication channels to such parties is thus essential since communication is one of few measures apart from brute force that is available as a mean for affecting the situation in the desired direction. The informants refer to the ability to establish such relations as a skill, a skill that not everyone posses.

The second overarching category, The experience of mediated communication, begins with a brief discussion of information systems and their effect on communication. The conclusions from paper 3, that information system design, even with ever as good intentions, often will cause contradictions
The communication problem. Yes, to know the person is... …I think the biggest communication problem. It is the one that one has to conquer quickest. The material communication problem, bad radios and everything is a technical issue it is only a material question and replace but to know the person is the biggest obstacle in... in communication. Independent of rank or nationality or staff.

The paper ends with a discussion about human–human communication and its relation to CSE and similar theories that originate from cybernetics. The three issues presented at the beginning of the paper is presented and discussed one by one. It is concluded, both from the theories presented and the examples provided, that social relations, and thus common ground, is an important facilitator for efficient communication. The relativity of efficient communication is discussed in the perspective of different theories concerning what enables a cognitive system to be effective. It is argued that efficiency in a system where humans take a central part perhaps not is the result of fancy interface design or perfect decisions, but rather an effect of how well the relations between actors in the system work.

The argumentation ends by raising a warning against the descriptions of communication in systems descriptions. In such descriptions, the parts that are characteristic for human-human communication are often left out, leaving the illusion that such communication works as easy and efficiently as data exchange in a machine system. To simply have a channel and a medium available is thus not sufficient to achieve successful coordination in a socio-technical system. Only if the intricate social mechanisms that underlie human-human communication can be understood, is it possible to understand what constitutes successful coordination, and thus control.
4.6.4 Discussion of paper 4

As declared, paper 4 is based on material that was gathered more than ten years ago. This fact could be used as a criticism against the paper, since the conclusions to some extent concern information technology, which we all know has changed dramatically during the last ten years. It could therefore be argued, as it often is when technology is concerned, that later systems, perhaps existing today, would be less prone to the concerns accounted for by the informants. This is however not likely, since the technologies discussed serve about the same functions as they did today, even though the interfaces and capacities may have improved (or deteriorated!) since 1994. Another point is that although technology may have improved, the amount of technical devices connected to an information system that a commander faces today probably has increased significantly in comparison with ten years ago.

Another problem, which also is discussed in the paper, is the fact that the material is based on interviews. Any interview, even when being open ended, is influenced both by the interviewer as well as by the informant. The interviewer may unconsciously direct the questions in a certain direction, and the informant may have some own agenda for answering in a specific way. Further, the informant may also, without being aware of it, try to respond in such a way that it fits the questions given in order to maintain a friendly atmosphere. Conversely, the informant may feel uncomfortable and avoid mentioning things in his/her answers. As stated in the paper, an attempt to cross-check statements was done already in the gathering of the material by choosing informants with different roles and different locations, so that the same phenomena and events could be viewed from different angels. However, no large discrepancies between the statements made by the informants were found. It should also be noted that what is reported is what people think about technology and communication. This is not necessarily the same as what they would do in an actual situation with an actual tool. Opinions can always change over time.

The selection of excerpts is another consideration. As in all qualitative research, it is possible to question the basis for selecting certain parts of a large corpus. In this case, it is specifically stated that the analysis is theory informed, meaning that the analysis focused on certain aspects of the material rather than a pure bottom-up approach. The excerpts were chosen because they are representative of the categories to which they belong. The fact does however remain that another researcher might have selected dif-
Chapter 4. Summary of studies


different excerpts. This criticism is hard to avoid, and the reader, as any reader of a study of this kind, should be aware that the analysis as well as the excerpts chosen for a paper always is dependent on the judgment of the researchers that produced the paper.

The level of transcription is of course a subject for discussion since the analysis largely is based on them. Transcriptions can always be made with more or less precision depending on the purpose of the specific study. An easy way to avoid criticism on this point is to use a very fine level of transcription, with micro-pauses, intonation, overlapping speech etc. In this case, the transcripts were made with a low level of detail, perhaps corresponding to level 1 as described by Linell (1994), a very basic level. Since the focus of paper 4 is what the informants say rather than how they say it (Silverman, 1993), that level of detail should be sufficient for the analysis.

4.6.5 Contribution of paper 4

The paper contributes by providing empirical accounts on the specific characteristics of human-human communication from a real-world practice in a complex, high risk setting. The importance of establishing relations and common ground has been discussed and exemplified, as well as the importance of physical meetings in that process. Accounts of experiences from technically mediated communication are also provided. It is suggested (by the informants) that personnel working in the kind of operations discussed in the paper prefers a multitude of channels and media, even though this is potentially both confusing and time-consuming.
5. Discussion and Conclusion

This purpose of this chapter is two-folded. Firstly, the research aims presented in paragraph 2.5 will be revisited and discussed in relation to the results of the papers included in the thesis. Secondly, the results will be discussed in relation to the theoretical background presented in chapter three. The purpose of this is present an elaborated theoretical fundament on which the suggested future research can be founded.

5.1. The aim of the thesis and the included studies

The thesis aimed at “describing the role of information technology for communication in joint control of dynamic situations” (see 2.5 above). From this, three more specific issues were identified.

The first issue concerned “How new forms of information technology affects joint control tasks in dynamic situations, and if/how microworlds can be used to investigate this.” As can be heard from the formulation, the reasoning comes from the fact that new information technology in some ways affect the way people can work when trying to control a dynamic situation. The papers that focus on this issue are:
Chapter 5. Discussion and Conclusion

Paper 1 (Johansson & Granlund, 2001). In paper one an attempt was made to investigate the effects of a new form of information technology (shared representations). Since it was very difficult to test effects of a technology that did not exist other than on a conceptual level, and also in an environment that only was a prototype, microworlds were suggested as a way of testing some of the ideas. The way of providing feedback about what was going on in the field to a controller/decision maker in an envisioned, high-tech command post was the main issue in the paper. Two conditions were used, one where data about unit positions and environmental data was transferred directly to the staff via a share database, and one where all information was distributed via e-mail. The first condition thus could provide both accurate and almost real-time data, suggesting that the personnel working in the staff would have a good basis for decision-making/control. It was found that:

- No clear differences between the teams in terms of performance. The measure was the amount of area that could be rescued from a forest fire in the C3Fire simulation.

- That the staffs that had access to the shared database were provided with faster and more accurate data than the teams that communicated solely via e-mail.

- That the variance within the teams in that had access to the shared database seemed to be larger than in the teams having to base their understanding of the “world” on e-mail communication.

- That the work processes the teams engaged in differed in the two conditions. The staffs receiving update seemed to be “chasing the situation” rather than plan ahead to a larger extent than the teams having to communicate in a more traditional fashion.

Paper 2 (Johanson, Persson, Granlund & Mattson, 2003). In this paper, the study performed in paper 1 was used to discuss the experiences from using microworlds as a tool for studying information technology in command and control research. It was found that:

- Microworlds seemed like a promising tool for investigating effects of new technical or organisational solutions in situations where it was inappropriate or impossible to perform real-world trials.
- If a researcher is to fully understand why a certain condition leads to a certain performance, it is necessary to study process and outcome. This can be done by combining quantitative measures with qualitative approaches such as video observations.

- The use of “professional” participants in such studies was found important, as well as the fact that those users accepted the simulation as an analogy for their normal work situation.

- That having observers with the same background as the participants could be a useful way of generating hypothesis or identifying phenomena that otherwise would be missed by the researchers. This was attributed to the fact that researchers often lack the “professional vision” of the domain expert, and thus simply do not see the same things as the “expert” in a situation.

Has the research question been answered by the two papers? The answer must be “partly”. The papers do not answer the general question of “how information technology affects joint control”, but they provide a suggestion to how such issues could be investigated. The usage of microworld is a way of approaching this field that provides a possibility to investigate the effects of new technology in a dynamic control task without having to create complex simulators. It must however not, as pointed out in paper 1, be forgotten that one has to be cautious when drawing conclusions from microworld research. This is because it is difficult to tell whether the observed effects and behaviours only apply to the microworld setting. That comment is however applicable to almost any simulator or training/testing situation. It is however true that if the usage of information technology is to be understood, we have to study real-world use of such systems, leading us to the second research issue.

**The second research issue** concerned “What the characteristics of actual use of information systems for joint control are in dynamic situations”. This question is, as stated in the introduction, similar to the first question, but concerned the way people actually use systems in reality, and the ways they adapt themselves or their tools so that they are usable in cooperative work situation in a dynamic environment. The papers focusing on this issue are:

*Paper 3 (Johansson, Artman & Waern, 2001)*. This paper described several situations where people adapt both their ways of working as well as the technology they use in order to cope with an unpredictable environment. The paper especially focused on the dichotomies between what is desired
and what is possible in a situation. The paper reported the following main observations:

- Information systems may, depending on how they are designed, reduce the operator to someone who provides input to the system. The risk of this is that maintaining the database thus become the primary activity rather than solving the task at hand. In the provided examples, the paper shows how operators develop cooperative strategies to cope with both the input to databases as well as the current activity.

- Modern systems are often designed in such a way that the operating environment becomes more silent due to the fact that large parts of the interaction in the activity is mediated by “silent” media such as e-mail or shared databases, even when the physical setting is designed to promote cooperation. In the provided example, it is shown how overhearing other persons are crucial to cooperation within a team in an emergency call centre.

- The hunt for exact (mimetic) representations of situations was criticised. Such representations both introduces the risk that operators start chasing the situation rather than handling it, and because representations rather should be representations for action rather than mimetic. A useful representation should elicit discussion as well as support the directing of external actions.

*Paper 4 (Johansson & Persson, submitted)*. The study presented excerpts from interviews with informants that had worked together in a complex situation viewed information technology and what kind of technologies they desired in certain situations. The informants reported that:

- There is a risk that the operators in an environment are distanced from the world since they interpret the presentation given by the information systems as a direct representation of the world. Examples in the paper discuss situations where this happened.

- That a multitude of communication technologies (both in terms of channels and media) is desired in the kind of dynamic activities reported, since it is hard to predict what kind of communication that is going to be needed in advance, or if it even is functional in a specific physical environment.
The papers have provided valuable insights related to the research question. It seems like many information system designs are based on assumption from rationalistic or mechanistic views on activity that not always correspond to reality. The human ability to adapt both to technology as well as the situation at hand is what makes things work in practice. The dynamics of a situation is also an important factor that influences the when and why a special kind of technology is desired or even when it is going to function properly. The research question has been answered in the respect that a number of observations of information technology use in dynamic, cooperative control tasks have been reported, providing a basis for reasoning and discussing about these issues.

The third research issue that was addressed was “What the pre-requisites are for efficient communication in joint control task and especially in dynamic, high-risk situations?”. The paper addressing this was:

Paper 4 (Johansson & Person, submitted). In paper 4, there are several reports from informants working together in a dynamic, high risk environment. The paper discussed:

- The relativity of efficient communication. Simply having a technical infrastructure for communication available does not say very much about the quality or the efficiency of the communication that is mediated.

- That the largest problem concerning communication rarely was technical, but rather one of knowing and understanding the person with one was to communicate.

- The importance of social relations and common ground. If two persons are to communicate and cooperate over a distance, mediated by communication technology, it was reported that this is much easier if the persons had a relation to each other and a shared understanding of each others working conditions. A number of examples were provided where the informants describe how they established and maintained relations that were the basis for communication with other persons.

- The potential risks of technically mediated communication. Different kinds of information systems provide different possibilities to interpret a situation. There is a risk that the picture provided by the available media and channels are interpreted as the reality, leading to
false conclusions about the state of affairs. The dynamics of the situation also makes it difficult to tell in advance what kind of media or channel that is going to be useful in the situation. This calls for flexibility in form of a multitude of channels and media.

- The risks of analysing or describing systems based on purely technical or cognitive approaches, since such approaches often fails to understand the distinctive features of human-human communication and social interaction.

The research question was answered in the respect of providing an example of what the pre-requisites for communication were in a specific situation. This does not mean that the same pre-requisite apply to other situations, but the paper points to some crucial aspects of human-human communication. There has been a recent interest in this area, by for example Klein et al (in press), but the importance of the social dimension of a cognitive system clearly needs more attention.

The three questions presented above reflects the evolvement of the thesis work, which has gone from the specific (how control is affected by new information technology), towards a holistic perspective on cooperation and communication in a JCS. In the initial work with the microworld studies, questions arose that were difficult to answer without looking into real-world practice. The data analysed from such settings lead to the insight in the importance of understanding the characteristics of human-human communication and what the pre-requisites for such communication are.

Below follows some conclusions from the studies put in relation to the theoretical framework presented in chapter three. First, some conclusions regarding communication in a JCS are presented, then a section reflecting upon the socio-technical aspects of a JCS follows, and finally a section discussing the usage of microworlds.
5.2. Some conclusions regarding communication in a JCS – the communicative infrastructure

Based upon the performed studies of joint control in the papers and the theoretical background presented in chapter three, some conclusions regarding communication in a JCS can be drawn. In a system comprised of several humans, the ability to control depends upon the ability to coordinate action. This coordination is normally achieved by communication. Communication between humans in turn depends both on inter-human relation aspects, organizational factors, and technology to function efficiently (Johansson & Persson, submitted). The pre-requisites for communication between humans can be described in terms of a communicative infrastructure. The communicative infrastructure can be described in terms of relations, organisation as well as communication technology. These “layers” can be viewed (for the sake of analysis) as individual but yet inter-dependent systems (see figure 11).

![Diagram of communicative infrastructure](image)

*Figure 11. The communicative infrastructure. The social, organisational and technical layers.*
Figure 11 illustrates a number of important things. We must remember that although the organizational and technical layers are more static than the social layer, which is based on constant interaction between the involved actors, they still may be subject to sudden changes. In the examples from the UN mission described in Johansson & Persson (submitted) there were occasions where the physical setting as well as available resources had a direct impact on the structure and availability of technical means for communication. Likewise, the organisation may also change over time due to circumstances specific to the situation. The structure of the social layer is nevertheless more dynamic or volatile. Firstly, the involved agents relations to each other evolves and changes over time depending on the interaction between them. Secondly, relations in a dynamic control situation are often context-specific, meaning that a person in one situation chooses to contact a specific person, but may chose another person in another situation, depending on the task at hand. So, while there may be a pattern of interaction that is prescribed in the organizational layer, the social layer may override this, particularly in dynamic situations. Some informants in the paper by Johansson & Persson (submitted) especially mentioned this when they stated that it is important to have the possibility to choose with whom one wants to communicate in critical situations rather than having to follow predefined patterns. The three layers can thus illustrate the conflict between what is desired and what is possible when conflicts emerge between the social, organisational and technical layers in a JCS. As pointed out in paper 3 (Johansson, Artman & Waern, 2001), it is often the humans in the system that have to adapt. In the the paper, there are several examples of how operators in a JCS adapt and cooperate to be able to cope both with the technical systems as well as the dynamics of the situation. From a systems design, as well as research, perspective, it is also an oversimplification to only consider one layer of the communicative infrastructure. As stated in the fourth paper (Johansson & Persson, submitted) “Only if we can analyse and understand the intricate social mechanisms underlying human-human communication is it possible to understand what constitutes successful coordination, and thus control”.

The social layer is probably the biggest challenge in the design and study of Joint Cognitive Systems. Although it is theoretically possible to define how people should interact ideally (organisation) and provide the technical means for it, it is very difficult to arrange things so that the inter-social aspects work smoothly. The communal and personal aspects of common ground (a basic pre-requisite for communication) are perhaps the ones that are most difficult to establish.
The common ground is needed as a basis for performance of a task including more than one actor so that it can be achieved with a minimum of friction. The notion of “construct” as described by Hollnagel (1998) is related to Clark’s (1996) description of common ground. I see these two notions as compatible, although developed with different foci. If we view the joint activity in which the common ground is used as a control activity, the connection becomes clear. While “common ground” is described as the smallest shared understanding of a situation, the “construct” is described from an individual operator’s perspective. The common ground can thus be seen as a part of the constructs of two persons, which constantly gets updated in the interaction between the persons (see figure 12).

Figure 12. Two individuals jointly controlling a process. Modified from Hollnagel (1998).

It is especially important to take this into account in tasks where the available time is limited since the establishment of constructs/common ground demands time as well as resources. In organisations that have time to prepare themselves for a situation, this is often done through training and other forms of interaction, giving a basis of understanding that allows the participants in the activity to focus more on handling the current situation. How people establish and maintain common ground in less well prepared situations is discussed in the fourth paper (Johansson & Persson, submitted). In the paper, several accounts that show how commanders in a com-
plex and dynamic reality manages to stay in control by various informal practices aimed at establishing and maintaining relationships, within as well as outside the JCS to which they belong. In fact, their ability to exercise control to a large extent depends on their ability to establish working relations with other agents in the system. In the paper, the informants describe how that they see physical meetings as important when acquiring as well as maintaining a common ground. Meetings between individuals in their everyday context give a frame of reference for future conversations, and also a basic understanding of their work conditions. This is valuable if a person for example is to give an order or negotiate, since it helps the person in creating a message that makes sense and provides motivation, based on the knowledge of the receiver’s background and situation. In the same way, the operators in the examples provided in paper three (Johansson, Artman & Waern, 2001) have developed various communicative practices to handle their situation. In the first paper (Johansson & Granlund, 2001), it is hypothesised that the fact that situational information is verbalised in the control environment is an important information source. The verbalisation makes it possible to not only overhear what is going on, but also, depending on who says it and in which tone, decide if its important or not. The ability to do so is naturally linked to how good an understanding the participants have of each other and their specific tasks and roles. Such knowledge is in turn formed during the interaction between the members of a team or an organisation. Technology that reduces the need for communication and interaction between team members may thus hamper the development of cooperative practices (Johansson, Artman & Waern, 2001).

5.1.2 Mediated communication

The role of mediating artefacts has also been discussed in the papers included in the thesis. While most control environments today are crammed with technology and the technological ability to process and transmit data seems ever increasing, the human ability to produce and interpret messages remains unchanged. A side effect of modern communication technology that originates from the digital computer's capacity to process and store is also that textual and formalised forms of messaging often is preferred in the design of information systems. This is appropriate in many forms of activities, but when facing an uncertain or rapidly changing environment, the needs also are subject to rapid changes and improvisation. From the interviews in paper four, it seems as if “general information systems”, possible
to use in any situation, is a chimera even in fairly restricted practices because of the fact that all organisation faces varying demands depending on the current goals and dynamics of the situation. Instead a variety in terms of communication channels and media was sought by the informants in paper four. The preferred view was to have the option to choose both the media and the connection (Johansson & Persson, submitted), so that it was possible to communicate with anyone in the way that was considered most appropriate depending on the situation. Likewise, the first paper (Johansson & Granlund, 2001) indicate that systems that makes it possible to transfer symbols from one representation to another with high speed and accuracy still are not necessarily superior to less technically advanced modes of interaction. Systems like the ones described in that paper, where information about geographical positions and events are presented on large screens, are becoming more and more common in crisis management systems today. If we view such a system as a source of information about positions and changes in the world, it makes perfect sense. If we instead consider the fact that such representations at the same time remove large amounts of communication that would have occurred otherwise in order to handle the task, it becomes more complicated. Although it is seemingly rational to reduce standard communication and increase accuracy, other information is lost at the same time. Things that earlier was revealed in the mere task of gathering the presented information is lost, like “who is driving the ambulance stationed in X-town”? “did the voice sound like he or she was under stress, or tired”? and so forth. The importance of having media available that permits spoken interaction was stressed by almost all informants in paper 4 (Johansson & Persson, submitted) because of these reasons. The type of system used for transferring data between humans will thus greatly impact how a situation is understood and handled.

5.3. Implications of the social on Joint Cognitive Systems

Any JCS composed of more than one human, or interacting with humans, is a social, or relational, system. Until the agents in such a system have “tuned” in to each other, or in other words established a common understanding of each other and the activity in which they are engaged, the performance of the system is likely to be unstable, or at least slow. The process of establishing a working relational system has several dimensions but the
shared issue is that the agents try to understand each others goals and understanding of the current situation, the common ground (Clark & Brennan, 1991). Relations are established and maintained in the act of communicating (Johansson & Persson, submitted), which is largely depending on social and cultural factors. The human ability to adapt to situations, and to each other, is large, but if there are organisational and technical boundaries between the participants in an activity, the establishment of relations will become difficult. As mentioned above, it is a dangerous fallacy is to believe that having a communication infrastructure amounts to having efficient communication between humans. The type of information technology, the media and the channels, will have effect on the way that it is possible to interact with each other (Gerbner, 1956), and thus to some extent support the process of grounding. This is probably also why the informants in paper four (Johansson & Persson, submitted) emphasised the importance of meeting other persons in non-mediated settings. But communicative practices can also be a way to compensate for designs that do not support a task in an appropriate way in information systems, as in the examples in paper three (Johansson, Artman & Waern, 2001). A part of the problem with designing information systems is that they (mostly23) are static and thus not adapt to circumstances. Hollnagel & Woods wrote in their paper from 1983 that:

“The goal for design in MMSs should be to make the interaction between the operator and the machine as smooth and efficient as the interaction between two persons. But it is an essential part of human communication that each participant is able continuously to modify his model of the other.”

(Hollnagel & Woods, 1983, pp 591)

Although this quote declares an important problem with design of a technical artefact, it also describes a very important human property, the ability to adapt. How large a variety a human-human system has depends on how well the components of the system are capable of coordinating their actions in time and space. This in turn depends on the components understanding/construct of each other. The constructs are based on the relation between the components. Control in a JCS is thus not only the effect of technical systems and competence of the involved personnel, but also the effect

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23 There are examples of technical systems that have the ability to adapt to pre-defined circumstances. However, such adaptation can only take place if the designer has been able to predict the situations, which is unlikely when discussing systems used in dynamic situations.
of a complex set of relations where explicit and implicit goals and norms of
the agents in the system play a crucial role. Technical systems should there-
fore be designed in such a way that they do not “hide” important aspects of
the interaction between human agents in the system. Arvola (2003) points
out that many situations where several persons are involved (as in the case
of a JCS) demands that technical artefacts can be used both as tools and as
media. He further points out that all actions performed in a joint activity
have practical, social and aesthetic aspects and that the tools shape the way
it is possible to perform actions. For operators working in a JCS in a critical
situation, this means that technical systems should be both transparent and
flexible to the operators working in it, so coordination and distribution of
tasks is supported. There are many examples where new technology instead
becomes more opaque and inflexible. A serious problem with this is that
such an approach hampers the human ability to adapt to other humans. By
reducing the feedback mechanisms that are unique to human-human com-
munication, be it face-to-face or verbal, the human agent also is reduced to
system components, expected to behave and respond in a rational and
mechanistic fashion. However, in actual work situations, designs that con-
strain the human ability to communicate in the desired way are often
worked around. Various forms of tailoring of the physical system or work
process are not unusual (Johansson & Persson, 2002). The human ability to
adapt to situations is often the factor that makes things work, despite tech-
nical constraints, dynamics of the task and contextual factors.

5.4. Some methodological suggestions
regarding the use of microworlds

Paper two discussed the role of microworlds as a tool for investigating the
effects of technology on human control over dynamic systems. Some meth-
odological considerations were provided. Dynamic systems are character-
ised by the fact that they present the controller with unforeseen events and
interactions. Even in very simple systems, it is difficult even for the re-
searcher to understand the interactions. Therefore the outcome of a control
process in such a situation may say very little about the work-process under-
lying it (Brehmer, 2004). In paper two (Johansson, Persson, Granlund &
Mattsson, 2003) we have suggested that it is important to study both out-
come and the process that leads to it has to be considered if one is going to
have a real insight in the work of an operator trying to control a dynamic

95
system. Although we cannot look into the heads of individual controllers and judge whether they are acting on a correct or false interpretation of the situation in which they act. However, we may, by analysing the interaction and communication in a team of commanders/controllers and the artefacts they use and then compare it with the actual development in the microworld.

The use of “expert” participants in studies aiming at investigating effects of technology or changes in the work process has been pointed out as an important issue earlier (Hoc, 1995; Rogalski, 1999). The idea that it is valuable to also have expert observers of a study/experiment has been added to this position in the second paper. The domain specific behaviour that “experts” exhibit is not always clearly visible to the researcher, since the researcher only is an expert on the microworld. Without the “professional vision” (Goodwin, 1994) of a domain expert, the specific behaviours of the participants in such a study may easily remain undetected or misinterpreted. Paper two describes how a shift in command style was identified and later could be traced in the log-files of the microworld that was used (Johansson, Persson, Granlund & Matsson, 2003; Granlund & Johansson, 2004). This example also points to the difficulty in analysing microworld log-files. Although all measurable variables in a microworld are known to the researcher, it is still very difficult to interpret them. If a microworld is made too complex, the researcher will soon encounter the same problems that he or she does in a field study, namely that it is difficult to understand what is actually happening. The benefits of combining log-files with other forms of data, such as video-recording, must not be forgotten. If the researcher is to understand not only that something happened, but also why, such additional sources data is invaluable.

In the case that we presented where expert observers were used, we believe that we have found a method that may help us understand some of the behaviours of the experimental participants. A problem specific to team research is the dynamics that emerge when a group of persons works together (Brown, 1988; Jones & Roelofsma, 2000). When a team of domain experts work together, a new factors are added, namely all the practices, expectations and norms that go together with their normal work. Although these are not always clear for non-members of the domain, it is likely that such factors will influence both the process and the outcome, and also that the usage of tools provided to solve the microworld task is going to be influenced by them. In paper one (Johansson & Granlund, 2001), we hypothesise that teams in one of the conditions can adapt to the task and divide
labour because of the similarity between the provided tools and the tools they use in their “normal” work. The hypothesis also stated that the other condition, where an “unconventional” form of technology is provided, makes it difficult, not to say impossible, to work traditionally since the tool provided not supports it. The time spent on training the participants in a study is therefore potentially even more important in an experiment engaging domain experts rather than for “novice” participants. This is especially important if the setting where the experiment is conducted is designed to resemble the normal setting in which the participants’ work, since violations of that setting could confuse the participants by violating the norms they are used to.

5.5. Future research

The field of cognitive systems engineering have focused on the composition of humans and machines as joint systems. How individuals use technical tools with the purpose of controlling has been the focus of not only that field, but also many others. However, the explosion of communication technologies that has occurred during the last ten years calls for a new focus on technology, not only as a tool for control of processes, but also as a mediator of communication in control activities. How communication between humans, with its specific problems and characteristics, should be incorporated in the concept of joint cognitive systems is an issue that deserves further attention. In a recent study by Farrington-Darby & Wilson (2005), these aspects are pointed out as perhaps more important than the cognitive:

“Whereas there has been much interest in technical skills and knowledge to perform work the social skills and knowledge of the social system has been given less attention. Through the study of railway controllers we were able to identify key steps of their work and where the challenges arise. These challenges were partly cognitive but were also related to the controller’s knowledge of the people with which they worked.”

(Farrington-Darby & Wilson, 2005, pp 12)

The suggestion for future research is thus not to abandon the basic ideas in cognitive systems engineering, but rather to expand the scope in order to incorporate the social and communicative issues into the framework. The studies included in the thesis have all provided evidence that this develop-
ment is needed. The need from this arise from the fact that the studies all concerned cooperative work involving several persons. The fact that systems in such situations often are used for mediating communication calls for a more holistic perspective on interaction that moves beyond “person working with tool” towards “persons working and interacting through tools”. This is needed not only in order to understand and analyse the behaviour of a JCS, but also if it shall be possible to design systems in such a way that they support coordination and cooperation.

5.6. Concluding remarks

This thesis has focused on the cooperative and communicative aspects of control over dynamic situations. The studies have pointed out the importance of understanding the characteristics of human-human interaction in a joint control task rather than focusing on the interaction between man and machine. The effect of different kinds of mediating technology on human-human interaction is from this perspective of great importance and has been discussed.

Microworlds have been suggested as a way of investigating the impact of new information technology designed to be used by teams in dynamic situations. Specifically, the importance of studying process as well as outcome has been discussed. The method of using observers with the same background as the participants in such studies has also been presented.

Finally, an elaborated discussion of the role of social, organisational and technological layers of a JCS has been presented, suggesting that more research is needed in order to incorporate the social and communicative dimension of human-human interaction into the field of CSE.
6. REFERENCES


New York.