Capturing Semi-Automated Decision Making
MARIA NILSSON

Capturing Semi-Automated Decision Making:
The Methodology of CASADEMA
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Abstract

This thesis presents a new methodology named CASADEMA (CApturing Semi-Automated DEcision MAking) which captures the interaction between humans and the technology they use to support their decision-making within the domain of Information Fusion. We are particularly interested in characterising the interaction between human decision makers and artefacts in semi-automated fusion processes. In our investigation we found that the existing approaches are limited in their ability to capture such interactions in sufficient detail. The presented method is built upon a distributed-cognition perspective. The use of this particular theoretical framework from cognitive science enables the method to take into account not only the role of the data captured in the physical and digital artefacts of the fusion system (e.g., radar readings, information from a fax or database, a piece of paper, etc.), but also the cognitive support function of the artefacts themselves (e.g., as an external memory) as part of the fusion process. That is, the interdependencies between the fusion process and decision-making can be captured. This thesis thus contributes to two main fields. Firstly, it enables, through CASADEMA, a distributed-cognition perspective of fusion processes in the, otherwise, rather technology-oriented field of Information Fusion. This has important conceptual implications, since it views fusion processes as extending beyond the boundary of physical/computer systems, to include humans, technology, and tools, as well as the interactions between them. It is argued that a better understanding of these interactions can lead to a better design of fusion processes, making CASADEMA an important contribution to the information fusion field. Secondly, the thesis provides, again in the form of CASADEMA, a practical application of the distributed-cognition theoretical framework. Importantly, the notations and definitions introduced in CASADEMA structure the otherwise currently rather loosely defined concepts and approaches in distributed cognition research. Hence, the work presented here also contributes to the fields of cognitive science and human-computer interaction.

Keywords: Decision Making, Distributed Cognition, Human-Computer Interaction, Information Fusion, Semi-Automated processes
Acknowledgement

“What was once a dream, became a goal, then a plan. Next, reality”

This thesis concerns capturing the interaction between human and technology within the context of information fusion. This domain has presented challenges and opportunities for interesting research, and I would like to take this opportunity to express my gratitude to all the persons I have met along the way.

First of all, I would like to thank my supervisor Prof. Tom Ziemke, for all the support over the years and continuous encouragements to believe in myself to become an independent researcher. I am indebted to my co-supervisors Tarja Susi and Joeri van Laere for their time, and discussions taking my research forward. My endless questions have always been patiently answered. Thank you! A special thank you also goes to my co-supervisor at Örebro University, Amy Loutfi, for providing valuable feedback.

I am also grateful to the industrial contacts at Saab Systems, FOI and Arlanda Air Traffic Control who made much of the research presented in this thesis possible. In particular, I would like to thank the operators at Malmö Maritime Surveillance Control and Arlanda Air Traffic Control who participated in the studies presented here for their time and interest.

Not to forget, special thanks go to my fellow graduate students and colleagues within the Information Fusion Program and the Cognition and Interaction Lab at the University of Skövde for making this a good research environment and fun experience. In particular, we were six, equally new to Information Fusion and starting at the same time, thus sharing all the ups and down: Alexander Karlsson, Maria Riveiro, Lina Nolin, Fredrik Johansson, Anders Dahlbom, and Christoffer Brax. With all your different backgrounds you always keep reminding me of the fun (and difficulties!) of interdisciplinary research.

And last, but certainly not least, many thanks go to my family for always being there for me. A special thank you goes to you, Serge, for your endless encouragement, support and advice whenever I needed it, making sure that I would finish. Hey, I made it!

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Technical Reports


Popular Science

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CHAPTER 1
The Thesis in a Nutshell

This chapter first introduces the research problem by presenting the area of information fusion based decision support together with an approach to capture human user interactions within such systems. In addition, a presentation of the overall research approach, in terms of its methodology, is followed by a focus on the contributions of the thesis to the areas of Information Fusion, Human Computer Interaction and Cognitive Science.

1.1 Capturing Semi-Automated Decision Making

Imagine there is an operator responsible for sending help to people in need after a major storm (for instance, a hurricane). The decision the operator needs to make is where to direct the next ambulance. Although, this can seem like a simple decision it is in fact rather complex. In order to make a decision, the operator must take into account information originating from different sources such as the location as well as the state of the people in need, the number and types of resources at hand, changes in weather, and so on. The operator needs to consider that the situation is dynamic and can change at any point in time (e.g., a road is destroyed). To make the decision the operator needs to integrate all the various bits of information originating from, for example, simulations (the possibility of a second storm occurring), human reports (what has been observed?), and various information systems (data bases, geographical positioning system, sensors, etc). Additionally, the information can be uncertain and conflicting. This leads to a potentially very complicated situation in which the operator must integrate and interact with many different information sources in order to make a decision while under high stress and time pressure, not to mention, the high information load. As technology becomes more and more advanced, there is an increasing possibility of supporting tasks, such as the above, with different types of decision support.
In particular, information fusion (IF) technology can be beneficial in such environments (Hall & McMullen, 2004; Hall & Llinas, 2001). Such technology can, for instance, automatically integrate information from different sources for decision-making and thereby decrease the amount of information the operator must deal with. Using such support can thus make decisions, like where to send the ambulances, more effective due to the increased possibilities of processing the information. Developing these support systems is however, not trivial.

A particular problem, from an applied cognitive science perspective as employed in this thesis, lies in how to capture the interaction between the operator and the different information sources and to determine how the information sources support the operator’s decision-making process. A good understanding of this interaction can lead to systems that are more effective since they are better tailored to the needs of the operators. Traditionally, however, there has mainly been a technological focus when developing IF based decision support with less attention on the use of it. The aim of the thesis is thus to fill this gap by proposing a new method, CASADEMA, based on the theoretical framework of Distributed Cognition (here after denoted DCog) (Hutchins, 1995a), to study that very interaction. DCog is a theoretical framework from Cognitive Science which seeks to explain cognitive processes as distributed between humans and the environment in which they are embedded. The method uses this very aspect to identify properties of the interaction and thereby be able to characterise the process and the interdependencies between the process and human decision-making. It should be noted that the method foremost presents an approach to understanding and describing the interaction, rather than being a design method to be used by engineers.

The main advantage of basing the method on a DCog perspective is that it implicitly opens the possibility of going beyond only investigating the fusion of the data captured in the physical and digital artefacts (e.g., information from a fax or database, a piece of paper with a list of attributes, etc.). It additionally allows us to account for the role that artefacts themselves play as cognitive support in the operator’s decision-making process. In other words, it becomes possible to obtain a detailed understanding of how the operator actually uses the information from the different sources. This means that the active user can be characterised as part of the fusion process. This method is thus shown to be an attractive alternative to the ones currently utilised within the domain.

The work presented here is clearly interdisciplinary, combining ideas not only from IF but also Decision Support, Human-Computer Interaction (HCI) and

---

1 DCog is used as an abbreviation to specifically refer to the meaning of the term Distributed cognition as introduced by Hutchins (1995a). This is in line with, e.g., Hutchins (2009), Halverson (2002), Rogers (1997), and Perry (2003), among others.

2 MARIA NILSSON Capturing semi-automated decision making
Cognitive Science. Consequently, this work contributes firstly to IF but also to the areas of HCI and Cognitive Science, as well as Decision Support as elaborated in Section 1.6. The subsequent introductory chapter presents the following:

- Research aims and objectives
- The motivation for the research in terms of research challenges
- Research process
- Research contributions
- Reading directions and chapter overview

1.2 Research Aims

The main purpose of this thesis is to present a study of the interaction between operators (decision makers) and IF based decision support (i.e., a real time (semi) automated decision support). In particular, the aim is to explore how such interactions between humans and technology (artefacts) within semi-automated IF processes can be captured. The goal of the research is thus to identify and develop an approach to capture such interaction. More specifically, the research question is as follows:

- How can the interaction between human decision makers and artefacts in semi-automated fusion processes (designed to assist decision-making) be captured if the purpose is to characterise the interdependencies between human decision-making and fusion processes?

1.3 Research Challenges

In the light of the above identified research question the following challenges can be identified. First of all, IF, as a research domain, originates mainly from the defence domain and is concerned with “the study of efficient methods for automatically or semi-automatically transforming information from different sources and different points in time into a representation that provides effective support for human or automated decision-making” (Boström et al., 2007, p. 5). The traditional focus within IF research has been on the technological methods of combining large amounts of (sometimes dissimilar) information into a more comprehensive and easily manageable form (Hall & McMullen, 2004). The JDL (Joint Directors of Laboratory) model can be used to explain the (fusion) process of achieving the representation on which the decision is to be based (Llinas et al., 2004; Steinberg & Bowman, 2001; Steinberg, Bowman, & White, 1999). Originally, the model included four levels capturing the technological process
from pre-processing data at the individual sensor through object, situation and impact assessment and process refinement (Llinas et al., 2004; Steinberg & Bowman, 2001; Steinberg et al., 1999). The model is further explained in Section 3.2.

The JDL model is the most commonly used model within IF research, and some even argue that all new research within IF needs to position itself in relationship to the JDL model (Hall, Hellar, McNeese, & Llinas, 2007). It is therefore clear that the model is very important for the IF community and has thereby defined the frame for the research performed within the community. However, this has, in part, led to some shortcomings as recently pointed out by Kessler and White (2009): “[t]he JDL model as it is currently represented focuses exclusively on the fusion domain and thus has contributed to the misperception that fusion could be an independent process … Another shortcoming of the JDL model is that the human role in the process is not represented except as an interface … The JDL model provides no way of explicitly tying automated data fusion processes to the perceptual and cognitive needs of the decision-makers, the individuals the automation is expected to support. This is a serious deficiency in the model, one that needs to be addressed” (p. 25).

This shortcoming has received increasing attention especially during the last couple of years and there have been attempts to accommodate the user in the JDL model by creating a fifth level dealing with user and cognitive refinements (Blasch & Plano, 2003; Hall, Hall, & Tate, 2001). This level is, however, far from accepted in the IF community, and not well defined (Hall et al., 2007). In the light of this research, the following challenge can be identified for this thesis:

**Research Challenge 1**: Perform research investigating the active role of users and the cognitive interdependencies existing in fusion processes and contribute towards overcoming the technological focus within the field of IF

Despite the lack of acceptance for the proposed Level 5 (cognitive/user refinement), there are thus researchers which explicitly considers a user perspective as important aspect of IF (Bisantz et al., 1999; Chan et al., 2005; Salerno et al., 2003; 2004). More interestingly, it is often implicitly assumed that the system will eventually be used for aiding human decision-making, in some sense. That is, they are implicitly treated as decision support, even though the name “decision support system” is not explicitly used. Claims to this effect include, for instance, the following: “data fusion processes are generally employed to support human decision making” (Steinberg et al. 1999, p. 432); “The purpose of a fusion system should be tailored towards supporting a decision-maker”
Chapter 1 Introduction

(Bossé, Guitouni, & Valin, 2006, p.1); “Ultimately, information resulting from the data fusion process is presented to the human decision-maker through a computer interface” (Bisantz et al. 1999, p. 1). There has thus been surprisingly little interest in investigating the potential of IF technology in supporting human decision-making (Hall et al., 2007). Some argue that the research is in fact being neglected (Hall, Hall & McMullen, 2009). As a result, the following challenge for this thesis can be identified:

Research Challenge 2: Investigate how IF systems actually support human decision-making in practice and thereby contribute towards overcoming the current trend to see IF technology as only peripheral to supporting decision-making

As previously discussed, there is no general understanding of how humans and technology interacts within IF processes. One of the reasons for this can be due to a lack of methods for studying this interaction. Currently, typical HCI methods have been applied in IF settings (Blasch, 2006). Researchers have for example theoretically compared decision-making models with the JDL model (Hall et al., 2007; Laere, Nilsson, & Ziemke, 2007). Others have focused on interaction in terms of interface issues. Studying the effect of using different interface modalities is one example of such research (Plano & Blasch, 2003). Researchers have also studied the effect of trust on user interaction (Bisantz et al, 1999) and performed experiments focused on specific cognitive abilities (Irvine, 2003). In addition, a few have focused on improving the design from a user (decision maker) perspective (Plano & Blasch, 2003; Bisantz, Rogova, & Little, 2004; Paradis, Brenton & Roy, 1999). What is striking is that although the current approaches have provided knowledge at a high abstraction level, they do not address the specific nature of interaction existing within semi-automated processes used in a decision-making context in terms of the cooperative nature of fusion process. This means, they have limited abilities with regard to capturing the interdependencies existing within fusion processes between human and technology. Interestingly, most of the methods mentioned could be traced back to traditional approaches in cognitive sciences where one often sought to understand how people do what they do without a proper appreciation of the tools they actually use in carrying out these tasks (cf. Chapter 4 for further discussion).

Hence, there is a need to complement the more traditional methods for analysing the interaction between humans and technology. Within Cognitive Science and HCI, there are a number of different theories which can be used to understand how human cognitive processes are organised, and how humans interact with their surrounding environment. These include: Activity Theory
Capturing semi-automated decision making (Kaptelinin & Nardi, 2006), Situated Cognition (Suchman, 1987; Clancey, 1997; Clark, 1997) and DCog (Hutchins, 1995a). In the context of the present work, the theoretical framework DCog (Hutchins, 1995a) is proposed as a tool to capture the interaction between humans and IF technology used to support decision-making processes. DCog attempts to explain how complex intelligent phenomena emerge from interactions between different components. This interaction can exist between different components in the brain, the body, and the social or material world (Hutchins, 2001). The focus of DCog (Hutchins, 1995a) is on understanding the dynamic flow of information through a system of components. From this perspective it means that human thought processes are explained by explicitly recognising the social and material world humans typically interact with as complementing an individual’s internal processes. As a simple, real-world example of a DCog perspective and its consequences, consider Wikipedia; if one adopts a DCog perspective, the knowledge captured within this online encyclopedia cannot be traced to one single individual. Instead it emerges from a collaborative effort (between different individuals and technology).

The reason why DCog (Hutchins, 1995a) is of more interest in the presented work rather than the other theories mentioned above is foremost its applicability in explaining phenomena within the IF domain. Most of all, we are interested in its ability to capture the distributed nature of the fusion process. That is, with a DCog perspective, the fusion process can be seen as naturally distributed between humans and technology. A DCog approach would in particular have a natural mapping and ability to explain the actual interaction between the components of the fusion process as it takes the socio-technical system as a unit of analysis (cf. successful studies of aircraft cockpits (Hutchins, 1995b; Hutchins & Klausen, 1998), air traffic control rooms (Fields, Wright, Marti, & Palmonari, 1998; Marti, 2000), vessel boards (Hutchins, 1995a), cardiac surgery (Hazlehurst, McMullen, & Gorman, 2007), emergency dispatch rooms (Blandford & Furniss, 2006), and co-ordination of collaborative activities (Perry, 1998)). In particular, the focus on representations also opens up for having a theoretical language which can be used to explain both processes within artefacts (technology) and humans. Moreover, one of the advantages with DCog is that cognitive processes become “visible” in the usage of artefacts as they are considered to be distributed between humans and the material world. Hence, by having a DCog perspective,

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1 All of these can be seen as a reaction to the more traditional view of cognitive science; as a consequence, the theories very much share the same ideas but differ in their implementation and interpretation

2 DCog uses the same theoretical language for capturing processes in individuals and artifacts (both are being treated as entities), but that does not imply that artifacts are considered as (biologically) cognitive (Halverson, 2002).
the cognitive processes involved in the fusion process can become visible. This together with the argument that “the cognitive system underlying decision-making in a particular context can be characterised by studying the representation that supports this decision process” (Cohen, Blatter, Almeida, Shortliffe, & Patel, 2006, p. 75, emphasis added) makes the DCog approach applicable. In addition, DCog has a process view and a focus on information which enables one to exploit the ability to capture the information (content) of what is being processed and thereby capture the fusion process. This altogether allows for a powerful tool to capture the (human/technology) fusion process.

Further, using DCog to study the interaction within IF processes can also address the fact that much research related to complex problem solving has focused on the individual’s mental processes and workload (cf., e.g., models of naturalistic decision making (Zsambok & Klein, 1997)), thus neglecting the role played by technology to support the decision-making process. It can be argued that a new perspective such as DCog is needed in situations where the cognitive process is extended to include both the environment and the role of artefacts in the decision-making process.

Traditionally, within Cognitive Science, DCog (Hutchins, 1995a; 2001) is a descriptive theoretical framework detailing a general theory about cognition. However, more recently, DCog has been developed into a structured tool for capturing various human-technology interactions (e.g., Blandford & Furniss (2006); Eden (2007; 2008); Ferruzca, Fabergas, & Monguet (2007); Galliers, Wilson, & Fone (2007); Rinkus et al. (2005); Wright, Fields, & Harrison (2000)). It has actually been argued that DCog needs to be formalised and structured to be able to effectively inform other disciplines such as Educational Learning (Moore & Rocklin, 1998). However, all of the methods have been developed to fit a particular situation (domain) and none of the methods mentioned above focuses on capturing semi-automated processes, as would be required in an information fusion domain (cf. Section 5.5.1). In light of previous arguments, defining what is an appropriate approach for studying interaction thus remains an interesting open research challenge. That is, for this thesis the following challenge can be identified for this thesis:

Research Challenge 3: Investigate the possibility to adapt DCog to suit the field of IF and in particular structure the DCog approach into a method specifically adapted to capture interactions in IF contexts, and thereby contribute towards overcoming the limitations associated with the methods currently used within IF to investigate interaction between humans and technology
To conclude, the work (i.e., the research question) presented in this thesis is motivated, and driven, by the above identified open research challenges. These challenges, and their relationship to the aims and objectives of this thesis, are further elaborated on in Chapter 11 Conclusion and Future Work.

1.4 Research Design

A qualitative method with an underlying research strategy of inductive analyses is used as the research seeks to provide insights and understanding of the nature of interaction (Patton, 2002). In particular, empirical investigations (based on theoretical studies) are emphasised in the development of the CASADEMA method, as illustrated in Figure 1.1 (cf. Blessing, Chakrabarti, and Wallace (1995)). The research process is further elaborated upon in Chapter 2. Three main documents, including this one, have been produced during the PhD studies: a research proposal (Nilsson, 2007), a licentiate thesis (Nilsson, 2008) and the doctoral thesis (cf. Figure 1.1).

The PhD progress as the progressive path towards developing a method to capture interaction

The research proposal included a characterisation of the problem domain. The licentiate thesis “Mind the Gap: Human Decision Making and Information Fusion” investigated, as the name implies, the gap between human decision-making and IF. This involved a characterisation of the two areas, as well as an exploration of possible interdependencies between them. In this doctoral thesis, the focus is partially on the characterisation of the interaction and partially on the development of the method for capturing such interaction. In practice, the PhD work has involved both empirical and theoretical investigations performed iteratively.
1.5 Scientific Contributions

At the present time, IF, HCI, Decision Support, and DCog are more or less separate research communities which have developed independently; however, there is a need to merge the ideas from the different communities to further develop the IF community. The presented thesis then contributes as interdisciplinary work. In particular, the qualitative research documented in this thesis seeks to contribute foremost to the IF research area/community by presenting a new method (cf. Table 1.1).

Table 1.1. Overview of contributions and corresponding chapter/publications.

<table>
<thead>
<tr>
<th>CONTRIBUTIONS</th>
<th>CHAPTER</th>
<th>PUBLICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 4 5 6 7 8 9</td>
<td></td>
</tr>
<tr>
<td>Main contributions</td>
<td></td>
<td>II, XV</td>
</tr>
<tr>
<td>Methodological</td>
<td>A method including a step-to-step instruction and notation for capturing interaction between humans and IF technology</td>
<td></td>
</tr>
<tr>
<td>Theoretical/Empirical</td>
<td>Characterisation of the IF process as it includes both humans, technology (artefacts) and the environment</td>
<td>II, X</td>
</tr>
<tr>
<td></td>
<td>Identification of decision making aspects of IF systems, i.e., the interdependencies between decision-making activities and IF process</td>
<td>V, VII, VIII</td>
</tr>
<tr>
<td></td>
<td>Characterisation of IF from a decision maker perspective (including a definition of a new decision support class and a decision situation model)</td>
<td>VI, IX, XVII, XIX</td>
</tr>
<tr>
<td>Additional contributions</td>
<td></td>
<td>II, XV</td>
</tr>
<tr>
<td>Human Computer Interaction/Cognitive Science</td>
<td></td>
<td>II, XV</td>
</tr>
<tr>
<td>Methodological</td>
<td>A specification of DCog in the format of a method which includes a notation, descriptions of concepts as well as an explicit focus on interaction in terms of information propagation and transformation of representational states</td>
<td></td>
</tr>
</tbody>
</table>

*The corresponding publications are listed at the beginning of the thesis.*
More specifically, we have put forward theoretical arguments regarding the applicability and the importance of a DCog perspective on IF (cf. Section 5.5) which have been further reinforced in two empirical case studies (cf. Chapter 7-8), and realised in the format of the method of CASADEMA (cf. Chapter 9). Additionally, a human decision making perspective has been promoted throughout the thesis. In addition, the aim of the research is to go beyond the typically defence perspective present in IF research (cf. Table 1.1).

The basic idea of using DCog as a theoretical framework to understand the interactions is not considered novel by many HCI and Computer Support Collaborative Work (CSCW) oriented researchers (e.g., Liu et al., (2008); Halverson (2002); Hollan et al., (2000)), and the very idea of using DCog to gain insights into a decision-making context may not be new to some (e.g., Cimino (1998) and Patel, Kaufman, & Arocha (2002)). However, it is still worthwhile to examine its applicability in an IF context as it portrays a semi-automated processes utilised in decision-making context. Similarly, there are previous attempts in developing DCog into a more structured method (Blandford & Furniss, 2006; Eden, 2007,2008; Ferruzca et al., 2007; Fields, Wright, & Harrison, 1996; Galliers et al., 2007; Rinkus et al., 2005), however none of these accounts for semi-automated fusion processes within a decision-making context.

1.6 Delimitation of Scope

The thesis is concerned with IF from an applied cognitive science perspective. This influences what can be found in the thesis. In other words, there will be no technological details regarding the computational components of an IF system. Ontological (cf. Blasch & Plano, 2003a) and other linguistic questions regarding user interaction are also not touched upon including various agent modelling approaches (cf. Lambert, 2009). Also, this thesis is not about how to design an IF system. Furthermore, we will not, for instance, consider the discussion of whether “information fusion” and “data fusion” is a subset of each other or, in fact, synonymous (cf. Steinberg, Bowman, and White (1999) which use the expression “(Con)fUSION of terminology”). IF is chosen as a term to be used throughout the thesis to refer to the information and data fusion community. Thus, the discussion of the transformation between data, information and knowledge is not touched upon. Finally, a discussion about what the right “labels” should be for the levels of the JDL model, e.g., should level 2 be denoted situation assessment (Llinas at al., 2004) or situation refinement (Steinberg, Bowman, White, 1999), is also beyond the scope of this thesis.
1.7 Organisation of the Thesis and Reading Directions

The background of the work is presented in Part I (Chapters 1-2), as it provides an introduction to the thesis and an overview of the research process. The theoretical grounding (Chapters 3-5) and the empirical grounding (Chapters 6-8) of the developed method are presented in Parts II and III. The method itself is presented in Part IV (Chapter 9). Part V includes a discussion (Chapter 10) and a conclusion (Chapter 11). In general, this thesis is written to accommodate readers with basic Human Factors/Cognitive Science/HCI knowledge, but no or limited knowledge of the IF domain and DCog. More specifically, the thesis is structured as follows:

PART I: Introduction

Chapter 1 introduces the work presented in this thesis by describing the motivation, the aim and objectives of the research, as well as the research process. The contributions are also highlighted.

Chapter 2 describes the overall research methodology in terms of chosen research philosophy and strategy. The research process adapted for developing CASADEMA is outlined and the overall assessment of the research is presented.

PART II: Theoretical Grounding

Chapter 3 provides a literature review which describes and defines central concepts within IF research such as fusion, decision support, user environment, HCI, and decision-making. A new decision support class which highlights a decision maker’s perspective in the context of IF is advocated. This chapter is mainly intended for readers with limited knowledge of IF.

Chapter 4 presents a literature review which explores the question: how can one study interaction? A short presentation of different methods used in IF and HCI as well as approaches for capturing human decision-making and interactions with semi-automated systems are provided.
Chapter 5 introduces a literature review which describes the theoretical framework of DCog. Both its theory, application in different disciplines and its method are considered. That is, this chapter describes the main theory upon which CASADEMA is built. This chapter is primarily for readers with limited or no prior knowledge of DCog.

PART III: Empirical Grounding

Chapter 6 provides several empirical studies which examine the usage of IF technology performed early in the PhD process. The chapter provides valuable insights regarding the need for and development of CASADEMA.

Chapter 7 provides an empirical case study describing the cooperative nature of humans and technology involved in the IF process. The case study, in terms of method, results and analysis is presented. The case study can be seen as the first version of CASADEMA.

Chapter 8 provides an empirical case study describing the decision-making activities intertwined with the IF process. The case study in terms of method, results and analysis is presented. The case study can be seen as the second version of CASADEMA.

PART IV: The method

Chapter 9 outlines a detailed description of the developed method, CASADEMA. It describes the cornerstones of the method as well as the exact procedure. Also the theoretical and methodological grounding of the method is considered.
PART V: Conclusions

Chapter 10 discusses the findings and implications of the research presented in this thesis. Aspects such as the value of DCog in IF and the level of formality vs. flexibility in DCog are thus considered. Also an assessment of the developed method is provided.

Chapter 11 provides a summary of the findings of the thesis. It also considers the open research challenges presented in the introductory part. A discussion regarding future work is also provided.
CHAPTER 2

Research Approach

This chapter details the chosen research strategy in general, and the chosen research process in particular. Finally, a discussion considering how the presented research can be assessed according to qualitative criteria is provided.

2.1 Research Strategy

The research question (cf. Section 1.2) of this thesis is complex. From the research question, it can be determined that we need a research strategy which can guide the research in answering “how” to capture the interaction and, thereby, how one can go about characterising interaction. In addition, the question partly belongs to the context of use (the domain of IF) and partly to the HCI discipline due to the nature of the question (studying interaction between humans and technology). Also, the focus on a particular user (decision makers who use the technology as support in a decision-making process) implies that insights from the area of Cognitive Science (including decision-making theory) are required. Providing the full picture of interaction, within a single methodology or discipline, can be difficult, an interdisciplinary research approach is thus required (cf. integrative pluralism (Mitchell, Daston, Gigerenzer, Sesardic, & Sloep, 1997)).

Furthermore, unlike most technology oriented theses presented within the context of IF (e.g., Muller (2006) and Peacock (2001)) emphasising a quantitative research, the present work emphasises qualitative research. In this context, quantitative research refers to a more experimental method in which known hypotheses and factors are tested (Patton, 2002). In such an approach, the environment is not allowed to play a part of the result. Qualitative research on the other hand, refers to studies of phenomena in depth and great detail (often in the context of its existence) (Patton, 2002). Since the research question emphasises the capture of interaction which emerge in the context of use, and that way is heavily influenced and affected by the environment, an experimental
approach is not suitable. Also, an experimental approach is not suitable because, as yet, there is no detailed understanding of the interaction between humans and IF technology, and hence, no possibility of beforehand knowing what characterises such interaction.

More specifically, a qualitative approach with *inductive* analysis has been chosen. An *inductive* analysis aims at exploration, discovery, and inductive logic (Patton, 2002). Inductive analyses contrast typical experimental designs which require specification of main variables and research hypotheses before data collection begins, meaning that the researcher needs prior knowledge about which variables are important and what kind of relationships exist (deductive analysis). Inductive analyses, on the other hand, allow the discovery of multiple interrelationships among emergent factors in data without defining the variables beforehand (Patton, 2002). Actually, such empirical research (e.g., observing real working systems) is notably lacking within the field of IF research. This is probably due to the lack of existing real world systems (beyond prototypes) and the general lack of user perspective (and the difficulties it involves) as well as the traditionally defence focus within the domain (which may hinder publication of the studies performed).

Moreover, in this thesis, a combination of *Design Science* (Blessing et al., 1995; Laurel, 2003) and *Case Study Research* (Yin, 1994) is utilised. In line with previous arguments, it is recognised that a single research strategy cannot provide all the answers; a combination of research strategies are needed.

*Design Science* (Blessing et al., 1995; Hevner et al., 2004) is a relatively new strategy involving processes and methodologies for the creation of methods, products and tools. Design Science is argued to be a multidisciplinary research approach influenced by, amongst others, Social Science, Computer Science, Engineering Science, and Management Science (Blessing et al., 1995). Design Research (Blessing et al., 1995) is, in particular, an interesting strategy due to its research methodology. The methodology involves three phases: defining a problem, designing a solution, and evaluating the solution (cf. Blessing et al., 1995). Furthermore, the individual studies performed are in line with *Case Study Research* (Yin, 1994) which involves, as the name implies, “a detailed investigation, often with data collected over a period of time, of phenomena, within their context. The aim is to provide an analysis of the context and processes which illuminate the theoretical issues being studied” (Hartley, 2004). Further, “case studies need to focus on analytical generalisation ... [i]n other words, the generalisation is about theoretical propositions not about population ... [r]ather, the argument is about the existence of processes, which may influence behaviours and actions” (Hartley, 2004).
2.2 Research Process

The chosen research process can be seen as involving three main interacting phases: (1) characterisation of interaction (2) development of a method (3) assessment of the method (cf. Figure 2.1).

This is in line with the development of the Design Research method in which one is required to go through three stages: (1) define the problem, (2) prescribe a solution, and (3) evaluate the solution (cf. Blessing et al., (1995)). It is also in line with the Cognitive Engineering approach (Hollnagel & Woods, 2005, p. 178) which works around three principles: (1) “identify the situation in which the problem exists”, (2) “describe the conditions associated with the problems”, (3) “propose or conduct the means by which such situation can be migrated or prevented”. More specifically, the following activities have been performed:

(1) Characterisation of interaction (defining the problem)
Chapter 2 Research Approach

- **Identification** of existing models and concepts within IF and human decision-making related to the identified research question
- **Investigation** of the interaction between decision makers and technology in semi-automated IF processes

The interaction has been investigated by combining theoretical and empirical studies. Theoretically, the implications of considering IF systems to be, fundamentally, decision support systems, are assessed (cf. Chapter 3). How to view the decision maker within the fusion process is also considered (cf. Chapters 3 and 5). Empirically, investigations of the actual interaction between decision makers and IF systems have been performed (cf. Chapters 6-8).

(2) Development of a method to capture interaction (*prescribe a solution*)

- **Identification** of existing methods studying interaction
- **Investigation** of which of the methods that can capture interactions as defined herein
- **Development** of new/adaptation of old methods to capture interaction as defined herein

The method (cf. Chapter 9) for capturing interactions has been developed iteratively, gradually emerging over both empirical and theoretical investigations. As illustrated in Figure 2.1, the development process started with a *Theoretical Study (1)* involving the identification of DCog as an approach for investigating the interactions within semi-automated fusion processes (cf. Chapters 4-5). A set of guiding questions were identified and used in *Case Study 1* (cf. Chapter 7). The findings from Case Study 1 (and implicitly the Theoretical Study 1) informed the *Preliminary Method*. *Theoretical Study 2* involved the assessment of previous DCog methods and a clarification of ethnography to strengthen the method (cf. Chapter 5). The findings from the preliminary method together with the Theoretical Study 2 informed *Case Study 2* (cf. Chapter 8). The findings from those studies can then inform the *Intermediate Method*. The method was then assessed, and the *Proposed Method* can be presented (cf. Chapter 9).

(3) Assessment of the developed method (*evaluate the solution*)

- **Identification** of existing possibilities for assessing the developed method
- **Validation** of the method by assessing it according to a chosen approach
- **Modification** (if needed) of the method in order to improve it
It has been argued that when a new method has been developed it needs to be validated (or tested and evaluated) (Blessing et al., 1995). One of the most prominent aims of the validation is to determine if the method has the expected effect (Blessing et al., 1995). In principle, it can be argued that the quality of a newly developed method can be ensured in two stages: (1) during the development of the method and (2) through empirical validations. Based on the outcome of these two aspects, a thorough assessment of the method can be done.

First of all, in the early stages of the development process, guidance from assessment criteria can be considered to ensure the method’s quality. Interestingly, the literature has yet to define a generally agreed upon set of standard criteria to inform the development of a method such as CASADEMA. Comparisons between methodologies that do exist typically have a rather narrow focus (see, for instance, the study on usability evaluation methods (Hartson, Andre, & Williges, 2003) or a study evaluating possibilities of theories for informing the design of CSCW systems (Halverson, 2002)). Hence, it is recognised that there is a need to develop a new set of criteria to be able to inform CASADEMA. Thus, in this thesis, ideas from HCI (Halverson, 2002; Hartson et al., 2003) and Human Factors (Annett, 2002) are combined to cover the scope of CASADEMA. The result of the assessment of the method is further elaborated upon in Chapter 11.

Moreover, as a consequence of the iterative approach used when developing the method, a continuous empirical assessment has been performed. That is, the method has been applied in different versions (cf. preliminary method and intermediate method) and improvements to the method have been made (cf. Section 9.1). That is, the method has been applied in practice and modified based on the outcome. Blessing et al., (1998) argue that “using the results [from descriptive studies] for the development of methods and tools can be expected to add more value to the results and lead to more useful methods and tools” (p. 51).

In addition, in an ideal world, it would be possible to assess the quality of a method by using it in parallel with others on the same data ensuring that the methodologies can be compared empirically and on equal terms. However, this would only test the method’s ability to capture the tested data but not its versatility. In this thesis, empirical applications of the method are described in Chapters 7-8.
2.3 Assessment of Research

The overall research presented in this thesis should be judged on its own theoretical basis, as argued by Lincoln and Guba (1985) who presented a set of principles specifically adapted to qualitative research to ensure the trustworthiness of qualitative research. These criteria should hence be used to judge the research presented in this thesis. They as follows:

- **Credibility** (i.e., internal validity) - Qualitative researchers should seek to establish the credibility of their findings, that is, the findings should make sense to the ones being observed/interviewed or within the context of the research being conducted. For example, throughout the studies performed, the findings were presented to the participants to ensure their correctness (i.e., the technique of “member checks” (Lincoln & Guba, 1985)).

- **Transferability** (i.e., external validity) - Instead of aiming for random sampling and probabilistic reasoning, the research should be described in such a way that it can be transferred to other settings, thus, promoting generalisation. It is the researchers’ “responsibility to provide the data base that makes transferability judgement possible on the part of potential appliers” (Lincoln & Guba, 1985, p. 316). In other words, researchers should provide a detailed description to allow others to judge the applicability of the findings in other settings. See, for example, detailed descriptions of the case studies performed in Chapters 6-8 and CASADEMA in Chapter 9. Details of how CASADEMA has been developed are provided in Section 2.3.

- **Dependability** (i.e., reliability) – Since it is difficult to replicate a qualitative inquiry, the aim should be to provide a trail (documentation of data, methods and decisions about the research) which can be used to judge the quality of the research. In this way, consistent findings could be produced, whether research was carried out as described, and factors that may have affected the results of the previous study were taken into account. See, for example, detailed descriptions of the case studies performed in Chapters 6-8.

- **Confirmability** (i.e., objectivity) - Qualitative research should also be judged according to the degree of its confirmation by the data. In this instance, objectivity is moved from the researcher to the quality of the data, that is, the evidence of the findings should be seen in the data. Again,
the importance of documenting the research process is emphasised so that a link between the data and the findings can be established.

2.4 Reflective Summary

The focus of this thesis is to investigate how one can capture the interaction between humans and artefacts in semi-automated fusion processes. That is, this research goes beyond the typically technological oriented research presented in IF by promoting qualitative research. In particular, it has been recognised that a multidisciplinary approach is required, combining insight from IF, HCI and Cognitive Science. Furthermore, a Design Science (Blessing et al., 1995) and Case Study (Yin, 1994) research strategy is highlighted as a promising way to investigate the presented research question. That is, through iterative theoretical and empirical investigation the presented research proceeds through three main stages: identify the problem, prescribe a solution to the problem and evaluate the proposed solution. One can argue that this approach can contribute to the validity and reliability of the method.
CHAPTER 3

Supporting Decision Making with Information Fusion

This chapter provides a literature analysis which introduces IF research and explores its use in the context of decision support systems. The chapter particularly highlights the importance of viewing IF systems as decision support systems when the aim is to better understand the interaction between the decision maker and the system itself. Such an exploration can be considered as the first step towards understanding the interaction between decision makers and IF technology in a human decision-making context. As Power and Sharda (2007) argue “[c]ategorizing decision support systems can assist researchers and managers in understanding how this general class of information systems impact decision behaviour and how one should design and construct such systems” (p. 1045). This chapter can thus provide insights for the development of a method to capture such interaction.

3.1 The Concept of Fusion

As noted by Hall and McMullen (2004), the concept of ‘fusion’ itself is not new. Humans and animals have used a combination of different senses to survive since the dawn of time. As humans, we have extraordinary skills which help us both to interact with the surrounding environment and to interpret situations and various pieces of information we encounter on a daily basis. As Hall and Llinas (2008) put it: “for example, assessing the quality of an edible substance may not be possible using only vision; the combination of sight, touch, smell and taste is faster and more effective. Similarly, when vision is limited by structures and vegetation, the sense of hearing can provide advance warning of impending dangers” (p. 1). As technology becomes more and more advanced, new possibilities of developing technologies based on the concept of fusion emerge,
creating so called IF systems. IF has particularly gained interest in scenarios that require dealing with a high information load and uncertainty. The main reason for the attractiveness of fusion functionalities is the possibility of exploiting the synergy between and integrating data from different sources in a similar way that humans currently do when we interact with our environment (explained above). This allows for the processing of huge amounts of data from many objects simultaneously in order to reach a presumably, better decision. This effect has been shown in empirical studies such as the ones illustrated in Figure 3.1 and 3.2 where the performance of the overall system improved with the number of information sources, that is, sensors (Hall & Linas, 2001).

![Figure 3.1 Illustration of the "fusion" concept. By using majority voting one could reach a better decision (cf., Condorcet’s jury theorem, Condorcet, 1785).](image)

![Figure 3.2 Illustration of the concept "fusion". By using multiple sensors registering different aspects of a particular object, a better understanding of the object can be achieved through fusion.](image)

### 3.2 A Historical Perspective

The role of the user in IF research becomes evident when considering the development of the most prominent model in IF community, the JDL Model (introduced in Section 1.4), whose aim is to capture the fusion process and provide a common language for researchers working within the field of IF. In addition to the JDL model, other models of the data fusion process have emerged and been proposed within the IF community, e.g., the Functional Model (Dasarathy, 1994); The Object Oriented Reference Model (Kokar, Bedworth, & Frankel, 2000); The Omnibus Process Model.
addition, the change of the user also becomes apparent when considering the treatment of human decision-making research within IF. Both aspects are explored in detail in the following.

**The Development of the JDL Model**

The first version of the JDL model was developed in 1985 (Steinberg & Boman, 2001; Llinas et al., 2004). The model comprises different levels which include the following functions (cf. Figure 3.3):

- **Level 0** pre-processes data at the individual sensors in order not to overwhelm the system with raw data
- **Level 1** combines data from different sensors to obtain estimates of an object’s position, motion, attributes, characteristics or identity. This function involves classic techniques such as target tracking and pattern recognition
- **Level 2** includes automated inference for finding relationships in the collected information (e.g., clustering of vessels in a specific group)
- **Level 3** involves predicting future states (e.g., predicting future location or activities of vessels)
- **Level 4** refines the fusion process as a meta-process controlling the previous levels 0-3.

![Figure 3.3 Early version of the JDL model (based on Llinas et al., 2004)](image-url)

(Bedworth & O’Brien, 2000); The TRIP (Transformation of Requirements for the Information Process) Model (Kessler and Fabian, 2001) cited in Hall & McMullen (2004). However, none of the models have achieved the same popularity as the JDL model. This may be due to the fact that the JDL model was the first one and that more recent models typically provide less of a holistic perspective than the JDL model. Also, the JDL model could be used for many purposes such as a tool to describe the research domain of IF as well as a tool for engineers to communicate regarding functions of IF systems which may have contributed to its attractiveness.
As previously argued, the model thus emphasises a technological process in which the user is only the receiver of information produced by the fusion process (cf. Figure 3.3). In other words, interaction is viewed as a one-way interaction, that is, the presentation of data without any feedback loop.

An extension “Level 5: cognitive refinement” to the original JDL model was suggested by Hall and colleagues in 2000 with the aim of explicitly accounting for functions associated with the human computer interface (Hall, Hall & Tate, 2000). They argued that there is a need to remove the “human computer interface bottleneck”. In this case, “human computer interface bottleneck” refers to the fact that broadband sensor data is fused through a narrow channel (the computer screen which the user interacts with), only to be analysed by a broadband human being. The interface thus becomes a bottleneck which prevents humans from using their extensive pattern recognition and analytical skills to infer the information presented. Level 5 thus encompasses both cognitive and human computer interaction issues. In other words, Level 5 focuses on the “interaction between the data fusion system and a human decision maker to improve the interpretation of results and the decision-making process” (Hall & McMullen, 2004, p.2). More specifically, Level 5 deals with “[m]onitoring the ongoing interaction between the data fusion [computer] system and a human decision-maker; optimization of displays, interaction commands, focus of attention to improve the human/computer effectiveness” (Hall & McMullen, 2004, p. 40). That is, Level 5 changes the output from the fusion process into displays and meaningful information for the user.

Figure 3.4 The JDL model including level 5 (based on Hall, Hall & Tate, 2000)

In the description of Level 5, specific technical aspects which can improve the design of the interface were suggested along with several recommended research areas (Hall et al., 2000). Amongst others,

- **Deliberate synthesis**: the concept of synthesisia (a condition in which affected humans perceive information from one sense using another; for instance by associating colours to sounds) should be explored when
designing interfaces to exploit the possibility of transforming visual representations to other types of representations such as sound.

- *Time compression/expansion:* human senses are especially good at detecting change. The development of time compression and time expansion replay techniques could assist the understanding of an evolving tactical situation.

- *Uncertainty representation:* visual, auditory and haptic techniques should be developed in order to improve the detection of uncertainty.

Based on the description of level 5 provided above, one can argue that the original intention for this level was to investigate how to support the user’s decision-making process through better designed interfaces. It should be noted that the level has only been described and research areas have been suggested, that is, the actual findings within the areas are still undefined.

More recently, Blasch and Plano (2002) suggested an extension by re-labelling Level 5 from “Cognitive Refinements” to “User Refinements” and thus created, the JDL- User model (cf. Figure 3.5). Level 5 is now defined as an “adaptive determination of who queries information and who has access to information (e.g. information operations) and adaptive data retrieved and displayed to support cognitive decision making and actions (e.g. altering the sensor display)” (Blasch & Plano, 2002, p. 270). In other words, one needs to consider not only the layout of the interface but also how the users should interact with the IF system. More specifically, *user refinement* operations can be seen as a set of functions of responsibilities in which the user can act in a variety of ways: monitoring a situation in an active or passive role, or planning by either reacting to new data or performing proactive control over a future course of actions (Blasch, 2006). Furthermore, according to Blasch and Plano (2002), the aim of Level 5, is to support *situation awareness, cognitive workload, attention and trust* (hence, to support the user’s decision-making process).

![User JDL model](image-url)

*Figure 3.5 User JDL model (Blasch & Plano, 2005; Blasch, 2006).*
Most importantly, Blasch and Plano (2002) showed that the user can be an active component in the information fusion process. That is, the most prominent difference between the two Level 5 additions to the JDL model is that the “user refinements” (Blasch & Plano, 2002) incorporate functions which allow the user to manually refine the fusion process. Hence, the considerations in Level 5 go above and beyond mere interface issues; users are now considered to be an active component of the IF system. This is further emphasised by a more recent version of the JDL model (Blasch & Plano, 2005; Blasch, 2006), illustrated in Figure 3.6.

Despite the recent inclusion of the user in the JDL model, it can be noted that the existence of Level 5 (including the later versions of the JDL model) is neither widely acknowledged by the IF community nor well explored (Hall et al., 2007). That is, “the fusion community has typically overlooked the role of the user by designing them out of the system” (Blasch & Plano, 2005, p.3). Most work to date has been limited to:

- theoretically comparing decision-making models with the JDL model (Hall et al, 2007; van Laere, Nilsson & Ziemke, 2007),
- studying the effect of using different interface modalities (Blasch & Plano, 2003),
- experiments focusing on one cognitive phenomena such as attention and trust to gain knowledge of that particular phenomenon (Bisantz et al., 1999; Irvine, 2003),
- considering methodological issues in how to incorporate users in IF projects (Bisantz et al., (2004); Bossé, Roy, and Wark (2007), Muller and Narayanan (2009), Paradis, Breton, and Roy (1999),
- performing different variants of task analysis to improve the design of the IF system (Bisantz et al., 2004; Plano & Blasch, 2003),
- exploring users as information providers in fusion processes (i.e., soft sensors) (Hall & Jordan, 2010).
To provide a more current picture of the present state of the user, a survey was conducted during the FUSION 2009 conference (see, Nilsson & Laere, 2009). The intention with the survey (which was questionnaire based \(^6\)) was to investigate the role of the user as of 2009, beyond what has been published. Among the responses, a consensus was found regarding how users have been incorporated in the development process. It was indicated that they are seen as part of the concept generation phase, the requirement gathering phase or the evaluation phase rather than part of the design phase. Also, the typical activities performed with users were found to be interviews and utilising users as advisers. However, the range of the responses also indicated that a consensus regarding what information is needed from users when automating a manual IF process is still lacking. Readers are directed to Nilsson and Laere (2009) for further details on the findings of the survey.

To conclude, the user’s (decision maker’s) role has changed over time from being a mere observer of information to being able to contribute and be a part of the system, theoretically, that is. Actual research findings beyond a description of the level 5 are limited. The practical application of the “level 5” including an understanding of how IF supports decision-making is yet to be produced.

**Human Decision Making Research within Information Fusion**

The change in the user’s role is also evident in how human decision-making has traditionally been portrayed within IF research. Consider the previously discussed JDL model, most often decision-making is viewed as a computation process in a computer and human decision-making is not emphasised. Moreover, in various handbooks and many research papers one most typically encounters references to Boyd’s (1987) OODA-loop (Observe-Orient-Decide-Act) and the Situation Awareness model (Endsley, 1995; 2000) (cf. Hall et al., 2007).

First of all, the OODA-loop (Boyd, 1987) is a decision-making reference model including the following activities (cf. Figure 3.7):

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\(^6\) The questionnaire (a single A4 page) was divided into four sections: (A) Your background, (B) Information fusion system development issues, and (C) Relevance of stated questions. Section B, which was the main part of the questionnaire, focused on four main topics: (1) Your experience of the developing processes? (2) Your experience of including the users in the developing process? (3) Your experience of using a modelling notation to capture user aspects in the development process? (4) Your experience of automating a manual information fusion process? The questions were given in a variety of formats including open ended (free text), multiple choice (tick boxes), and rating questions. 15 people participated in the survey (equally distributed in the categories (1-5) (5-15) (15 or more) years of experience).
- **Observe.** This is the first activity which involves observing the environment by noting distinguishing features. Originally, this activity referred to detecting an opponent’s aircraft.
- **Orient.** This activity positions the actor in the environment. It originally referred to the activity of positioning the aircraft towards the opponent’s aircraft in order to be in a good position for the next step, to make a decision.
- **Decide.** This activity involves deciding what to do next, based on the information from previous stages.
- **Act.** This activity basically means to carry out and implement a decision. Originally, this referred to the actual pressing of the trigger in the aircraft which would shoot down the opponent’s aircraft.

Figure 3.7 The OODA Loop (Boyd, 1987).

The activities are positioned in an iterative and cyclic way, with the first activity, usually, but not necessarily, being observe, and the final one (before a new observation begins) being act. There is no explicit end point in the loop, but it will terminate due to lack of input either when the action has been successful or when there is nothing more to observe. The aim of the model is to enable faster decisions by identifying both your own decision steps and those of your opponent, thereby enabling you to act before your opponent. Boyd (1987) showed that the American fighter pilots were superior their opponents in all four activities of the OODA loop, enabling them to “get inside” the opponent’s decision-making process (i.e., their OODA-loop) and win battles. The OODA-loop has its benefits, however, it is simplistic in its nature and fails to capture the dynamic nature of decision-making. For instance, it does not include any feedback loops. Actually, traditionally within IF, the decision-making process is often viewed in a sequential order, where one optimal/objective decision can be reached. It is argued that this is the most accepted and most referenced decision-making model within IF (Hall & Llinas, 2001; Hall & McMullen, 2004)), and is usually treated as a general model of decision-making.

Furthermore, Endsley’s Situation Awareness model (Endsley, 1995, 2000) illustrated in Figure 3.8, is a commonly used model, within the IF community, for capturing situation awareness (e.g. Blasch and Plano (2002); Bossé et al.
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Capturing semi-automated decision making

(2007); Salerno et al. (2004); Paradis et al. (1999); Hall et al. (2007)). Much of the model’s attractiveness to the IF community can be due to its similarity to the JDL model (i.e., from objects and their relationships we get an understanding of the situation which we can use to project future states). Situation awareness can be seen as a pre-stage of the decision-making process (cf. Figure 3.8). The model explains the core of human situation awareness and the various factors affecting situation awareness. The model is divided into three different mental processes, that is, perception, comprehension, and projection. Here, it is believed that situation awareness is a state of knowledge resulting from a process referred to as situation assessment, which is the process of achieving, acquiring, or maintaining situation awareness. In the IF community, having a certain level of SA is believed to be a requirement for making good decisions. It can also be noted that “mental models” are implicitly emphasised within the model.

![Figure 3.8 Endsley’s situation awareness model (Endsley, 1995, 2000).](image)

It can be argued that what the “typical” IF researcher knows about decision-making is typically constrained by the OODA-loop and the Endsley’s Situation Awareness model. More recently, however, the dynamic nature of decision-making has been emphasised by some within the IF community (e.g. Blasch (2006); Bossé et al., (2007)), moving away from the strict (static) nature of the OODA loop. Blasch (2006) refers to dynamic decision-making in terms of different decision modes (reactive, proactive, and preventive) which are based on research carried out by Waltz (2000). Blasch (2006) also mentions the Recognition Primed Decision making model” (cf. Klein, 1998; Klein, Calderwood, & MacGregor, 1989) as a suitable model from which to obtain a better understanding of the decision maker. Bossé et al. (2007) highlight naturalistic decision-making theories to understand how decision-making is done in the real world. Models mentioned include, but are not limited to, the recognition primed decision making model, image theory, the scenario model, and the skill-rule-knowledge model. Recent research has also tried to theoretically compare decision-making models with the JDL model (Hall et al., 2007; Laere et al., 2007). However, as the limited number of references imply, this is yet to
become main stream. That is, IF systems are still not treated extensively as actual decision support systems. In the following section, this is explored in detail by first introducing decision support in general and then IF based decision support specifically.

3.3 Decision Support Systems

In general terms, decision support systems (DSS) evolved during the 1970s and it refer to computer systems which are intended to support complex decision-making and problem solving. More specifically, a DSS can be defined as “a computer-based information system that supports either a single decision-maker or a group of decision-makers when dealing with unstructured or semi-structured problems in order to make more effective decisions. The DSS supports one or more decision-making activities carried out in a decision process.” (Alenljung, 2008, pp. 79-80). That is, a decision support system can have many different purposes and be structured in many different ways. However, Holsapple and Whinston (1996) argue that general aspects are to be found in any DSS. In their opinion, any DSS should exhibit one or more of the following characteristics in order to be named a DSS:

- contain knowledge describing aspects of the decision-maker’s environment, indicating how to accomplish a range of tasks, and valid conclusions in different circumstances.
- have the ability to acquire and maintain descriptive knowledge as well as other kinds of knowledge
- have the ability to present knowledge on an ad hoc basis in various customised ways as well as in standardized reports
- have the ability to select any desired subset of stored knowledge for either presentation or for deriving new knowledge in the course of problem recognition and/or problem solving.
- be able to interact directly with a decision-maker or a participant in a decision in such a way that the user has a flexible choice and sequence of knowledge management activities.
- be able to coordinate/facilitate interactions among multiple decision makers

There are two main groups of decision support (Power & Sharda, 2007): automated decision systems (e.g., systems which automate routine decisions in well-structured situations) and decision support systems (e.g., auxiliary and ancillary systems which assist decision makers). A further categorisation based on
the specific technology used within the decision support is as follows (Power, 2002):

- **Data-driven DSS** refers to systems which provide access to large amounts of structured data from databases in order to support manual analysis; that is, enabling the display and manipulation of queries to a database or data warehouse for specific questions.

- **Model-driven DSS** refers to systems which are based on different representational and optimisation models to support decision-making; that is, enabling what-if analyses.

- **Knowledge-driven DSS** refers to systems which consist of knowledge, an understanding of problems and problem solving skills within a specific domain; that is, enabling suggestions and recommendations for actions (i.e. expert systems).

- **Document-driven DSS** refers to systems which gather, retrieve, classify and manage unstructured documents; that is enabling the structuring of documents.

- **Communication-driven and Group DSS** refers to systems which support collaboration, communication and coordination between multiple decision makers; that is, enabling the facilitation of solutions.

- **Interorganisational/intraorganisational DSS** refers to systems which support the facilitation of information distribution of organisations; that is enabling service for users.

- **Function-specific or general purpose DSS** refers to systems which are developed to support a specific task or function; that is, enabling automated support for routine tasks or facilitating decision tasks.

- **Web-based DSS** refers to systems which are based on web technology; that is, enabling the delivery of decision support information or a decision support tool.

Although a DSS can have elements from different categories, it is possible to highlight one category as the ‘drive’ and focus of a particular DSS (Power, 2002). In general, it can be argued that, independent of the category, a DSS has a narrow, focused, and specific purpose.

In recent years, our abilities to access information have increased significantly. Additionally, technological advances are making it possible to build

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7 Similarly, a more recent and exhaustive list of characteristics and capabilities of DSS is provided by (Turban, Arson, & Liang, 2005). It should be noted that there is no general consensus of the components of a ‘DSS’, consequently, there is no general agreement regarding standard characteristics and capabilities of a DSS (Turban et al., 2005). One can however observe similarities between the different the lists.
new kinds of decision support systems which fall outside the traditional categorisation previously provided. IF in particular has gained attention within this context, given that “while information technology can transform a data poor situation into a data rich environment, the fact remains that data needs to be fused and analyzed effectively and efficiently, in order to provide appropriate information for intelligent decision making” (Tien, 2003, p. 104). In the following section, this new class of decision support, yet to be acknowledged, is be introduced in more detail, namely, information fusion based decision support.

3.4 Characterising IF Based Decision Support

Interestingly, despite the explicit acknowledgment within IF research, it is generally implicitly recognised that IF technology is used to support decision-making (Steinberg et al. (1999); Bossé et al. (2006); Bisantz et al. (1999)). The general aim of supporting decision-making can also be seen in recent definitions of the field (cf. Boström et al (2007) outlined in Section 1.3). During the years, there have been different attempts to characterise IF systems, see for instance, (Bloch, Hunter (2001); Bossé, Guitouni, & Valin, (2006); Dasarathy (1994; 2000)). Interestingly, however, none of them tried to classify IF systems as decision support systems, focusing instead on the technological aspects of IF. In the current literature, there is actually no general consensus on the components of an IF system, and consequently, no agreement of standard characteristics and capabilities of IF systems. This is at least partly due to the research domain still being relatively young (for instance, the annual IF conference celebrated its 10th anniversary as recently as in 2007). Despite the lack of consensus, one can look at the current literature produced within the field, from a decision maker’s perspective, and identify some general principles and characteristics which can constitute “fusion based decision support”.

Considering the previously mentioned list of DSS requirements in Section 3.3 provided by Holsapple and Whinston (1996), IF systems, typically fall within the listed requirements in the following way (Nilsson & Ziemke, 2007):

- IF systems have the ability to fuse information, and present it to the user for further considerations.
- IF systems contain knowledge of the environment due to data from different sensors, with the possibility of predicting future states.
- IF systems have the ability to acquire and store knowledge (information) from different sensors.
- IF systems can present new knowledge (information) due to the ability to fuse
- Users of IF systems could interact with the system influencing both the process and the result.
- IF systems could coordinate/facilitate interactions among multiple decision makers.

Hence, IF systems, in general, fulfil the requirements of being a decision support system set by Holsapple and Whinston (1996), and they can, indeed, be considered as decision support systems. Furthermore, looking at the characteristics of IF systems, IF based decision supports are typically function specific decision supports in terms of supporting real time decision-making and combine data, knowledge and model driven functionalities. In addition, it is usually a partly automated decision support with the purpose of supporting rather than replacing the decision maker. In the context of the previously mentioned classes of decision support, IF based decision support can therefore be seen as an additional class, combining several of the traditional ones. That is, considering IF systems in general, the following definition can be identified (Nilsson & Ziemke, 2007):

Fusion driven decision support systems, i.e. systems which are based on fused information from different sources such as sensors, databases and models, providing both automatic and semi-automatic fusion processes, i.e. enabling complex decision-making from large amount of information (which may be conflicting/contradictory or uncertain) without information loss (e.g., information is not just filtered, but, for instance, aggregated) with respect to the user’s decision-making process.

To consider IF systems as a specific class of decision support can highlight the additional value added to a decision support system by fusion. It can also, as previously argued, help researchers understand how this specific class of decision support, that is, fusion based decision support, affects decision-making. Before further characterisation of IF based decision support, an identification of reasons for the attractiveness of IF as decision support is highlighted.

3.4.1 The Basic Structure of IF Decision Support Systems

As a decision maker, one is interested in the general capabilities of the system. That is, we look in detail at the concept of fusion and define the general structure of fusion based decision support (cf. Figure 3.9).

In line with the general description of the class “IF based decision support” described in Section 3.4, fusion is the basic component of an IF based decision support system.
support. Looking at the existing definitions of IF, there is no definition with a
decision-making perspective (cf. Boström et al., (2007) which includes a
comprehensive list of definitions of data/information fusion used within the
field)⁹. In this context, a new definition was created which accommodated a
decision maker’s point of view. The definition is stated in Section 1.3. The aspect
which sets this definition apart from others is that it describes the process as well
as the goal of fusion from a decision-making point of view. That is, it defines the
goal of IF systems as creating a representation on which a decision can be based.
The definition helps to define the goal of an IF system as decision support. In
other words, the processing of the information (i.e., the actual process of
integrating the information from multiple sources into a format which can
support decision-making) is the core of the IF based decision support systems.

Furthermore, the basic component of an IF system, from a decision maker’s point
of view, is the fact that the system receives information from multiple information
sources which enable fusion. Information sources can be, for example, active
sensors (radar), passive sensors (infrared, visible, acoustic, magnetic and seismic),
human sources (intelligence gathering) or data archives (weather, financial data)
(Dasarathy, 2000). Alternatively, one can distinguish the different information
sources by classifying them as either past (e.g., databases), present (e.g., active
sensors), or future (e.g., simulations) information sources.

Also the interaction with these systems is characteristic. According to (Hall &
McMullen, 2004) one can observe the following when looking at the interaction
between the user and the system. In ordinary computer systems, the interaction is
typically either user-driven or data-driven applications, but not both. However, in
an IF based decision support, both modes of operation are often used
simultaneously (cf. Figure 3.9). On the one hand, data is received from sensors

Figure 3.9 A schematic overview of IF based decision support (Nilsson & Ziemke, 2007)

⁹ Fusion is also characterised in the following section in terms of the JDL model
and processed by automated fusion processes to be presented to the user in a timely fashion and without overwhelming him/her. On the other hand, the user is in charge of the system and can initiate interaction to retrieve information, perform computations and control the system resources. In other words, the decision maker can interact with the output produced by the system, and/or interact with the automated fusion process in order to refine the process (cf. the JDL model discussion in Section 3.2). It follows from this that IF-based decision support systems can offer different levels of automation depending on how much interaction with the system is required from the user. More specifically, in this thesis we identify the two ends of the scale.

1. Systems in which the users base their decision solely on the output of the IF decision support (i.e., a decision support with an automated fusion process).
2. Systems in which users can be involved in the process of creating the output on which the decision is based (i.e., a decision support with a semi-automated fusion process). In other words, a system employing user refinement functions.

In practice of course, this is a sliding scale and an actual system can fall anywhere between the ends of the scale. To demonstrate, the following are examples of functions decision makers can perform to refine the process and, thus, make the process more effective and efficient:

- The decision maker can contribute and aid the system with respect to the different JDL model levels (Blasch, 2003):
  - Select incoming data, i.e., determine what and how much data value to collect (Level 0).
  - Choose objects of interest, i.e., determine target priority and where to look (Level 1).
  - Define an area of coverage, i.e., provide context information (Level 2).
  - Determine the level of threats, i.e., define what is a threat and adversarial intent (Level 3).
  - Refine location of sensor placements, i.e., determine which sensors to deploy and activate (assesses the utility of information) (Level 4).

- The decision maker can refine the fusion process by being a sensor manager (Blasch, 2003):
  - Find the best course of action.
  - Establish what sensor to use and allocate resources.
  - Achieve the best combination of sensors.
  - Implement plans (activate sensors, delegate the system tasks, etc).
  - Control/evaluate the result of the process.
The decision maker can reduce the search space for the fusion algorithm and guide the fusion process (Blasch, 2006).

The decision maker can make the final judgement of identification, i.e., determine the correct object when a high degree of uncertainty exists (Bisantz, 1999).

The decision maker can make judgement regarding the correctness of estimates.

The decision maker can determine data needs, and thereby, cue the system by selecting the data of interest (Blasch, 2006).

The decision maker can reduce non-interference background processing (areas without targets).

The decision maker can alert to possible high-value targets in images for a larger set of images on the image deck.

In summary, the fusion process is complex and can involve both machine and human performed activities. So far, the basics of the IF based decision support have been described. To fully characterise the system, the following section describes the environment in which such systems exist.

### 3.4.2 The Attractiveness of Using IF as Decision Support

There are different reasons for wanting to use fusion from a decision maker’s point of view. Most often one mentioned the fact that information received from different sensors can be combined in such a way that generated more or better information than the original (Hall & McMullen, 2004). For example, to fuse information/data from different sources one can reduce uncertainty (comparing information from different sources), increase accuracy (information from different sources complementing each other) or increase robustness (the possibility for redundant information) (Bossé et al., 2006). That is, the authors emphasised the computational advantages and power of fusion (Bossé et al., 2006). From a more decision-making perspective, the following reasons can be highlighted.

**IF technology’s Ability to Overcome Decision Makers’ Cognitive Limitations**

Humans have cognitive limitations whose effects could be reduced by using IF technology that provides additional processing capacity. The aim is thus to facilitate or extend the human’s ability to process information (i.e., to acquire, transform, and explore information). For instance, “[w]ithout advanced data/information fusion architectures and techniques, the user, often resorts to viewing that data from a single sensor or single database viewpoint” (Akita, 2002, p. 1). IF technology is therefore often used in environments where decision
makers are either faced with a high information load, or in which the information can be conflicting and uncertain (Hall & Llinas, 2008). In such situations, the decision maker can be overwhelmed by the amount of information and, thus, has difficulties in reaching a decision (Hall & McMullen, 2004). By nature, the amount of information a human can process at any given time is limited (Eysenck & Keane, 2000). Using a technology which exploit the synergy between and integrates information from different sources, thereby reducing the amount that needs to be processed by the decision maker, can be beneficial.

As Akita (2002, p. 1457) argues: “[w]ithout data fusion, the user is faced with dealing with data that is redundant, inconsistent and conflicting ... To support the user, data fusion architectures must be examined to prevent/mitigate information overload and to expedite processing of the vast amounts of data”. Or, as Akita (2002, p. 1) continues to describe: “this situation creates a significant information overload to the users in many operational environments, when the data is presented in a ‘raw’ form”. Also, Steinberg et al. (1999) acknowledge the use of fusion for potentially refining and reducing information, in order to support human decision-making.

IF technology can also reduce the effects of human cognitive limitations by providing information that would normally be out of reach for the decision maker’s senses. That is, IF technology can be beneficial in environments in which humans might, for instance, need to “see longer” or “hear more”. This is often the case when there is a need to access an environment which, for one reason or another, is unreachable. This may be caused by practical problems (human vision in the dark is limited) or be due to security issues (it may not be possible to enter a military battlefield due to a significant risk of injury or death).

**IF Technology’s Ability to Increase Decision Makers’ Situation Awareness**

Humans can use IF technology to increase their situation awareness and thereby decrease the complexity of their decision-making processes. Having situation awareness (Endsley, 2000; 1995) is typically considered a prerequisite for making a decision. In these situations IF technology can be used as processing capability to provide an additional understanding of the situation at hand, thereby making it easier to reach a decision. For instance, Steinberg et al., (1999) acknowledge the possibility of using IF for refining and reducing information to support humans in their decision-making activities. Moreover, they argued that “[a]utomated data fusion processes are generally employed to support human decision making by refining and reducing the quantity of information that system operators need to examine to achieve timely, robust, and relevant assessments and projections...” (Steinberg et al., 1999, p. 432). In other words, a greater understanding of the situation (i.e., increase of situation awareness) can be achieved through the use of IF technology. As a consequence, IF technology is most often used to recognise a
need to make a decision (action); diagnose a problem, and analyse a decision situation at hand (i.e., support the decision maker to make judgement, evaluation, and choice) (cf. Alenljung, 2008). For instance, the decision maker lacks necessary information or problems with understanding the decision situation. In these cases, IF technology can be used to provide advice, expectations, evaluations, facts, and analyses about a situation on which a decision can be based. Moreover, IF technology can be used to analyse the situation, for instance, to enable humans to predict future states, and see relationships which not is immediately obvious to them. In the following sections, the basic characteristics of IF systems as decision support are provided.

3.4.4 The Decision Making Environment

In general, interacting with and/or monitoring IF based decision support is a challenging activity for humans. This is not only due to the amount of information, the high number of variables involved, or the opacity and complexity of the data mining techniques used in the detection process. It is also due to other factors, such as time pressure, high stress, inconsistencies, as well as the imperfect and uncertain nature of the information. In addition to the complexity of the decision environment, the IF domain often represents a situation in which decision makers do not have direct access to the problem situation at hand (i.e., access is provided through sensors and computer screens). Additionally, the decisions, once made, are implemented via computer screens and verbal communication with other team members (communicating through different medias, e.g., phone/email/chat). Furthermore, the interaction extends in time, involving past, present, and future actions and decisions as a variable in the current decision. Moreover, the technology involves partly automated processes. Overall, it is a complex situation.

Interestingly, there is no general view of the actual decision-making environment in which IF technology exists. That is, there is no formal description of the decision-making situation. The reason for that could be the broad range of IF decision support systems, and their different uses. Some issues are worth mentioning however. In the following we define the environment in which the interaction between the decision maker and the IF based decision support exists based on the current state of the art in the literature of IF. The findings are summarised in Figure 3.10. The figure is inspired by Paradis et al., (1999) who stresses the relationship between the user, the task and the technology. It is also inspired by the complexity chain proposed by Cummings and Tsonis (2005). During the review of IF research, a continuous classification of emerging insights

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10 An extended version of this section is published in Nilsson et al (2008).
and factors has been made according to the broad and inclusive categorisation displayed in Figure 3.10, hence, enabling an iterative development of the figure. The figure provides an overview of (a) a specification of categories and the relationship amongst factors affecting human interaction, and (b) specific factors related to each category.

**Figure 3.10** A schematic overview of a decision-making environment typically found in IF contexts.

In general one can abstract the typical situation for a decision maker, interacting with a typical IF based decision support, as follows (cf. Figure 3.10):

- The external environment *affects* the decision maker’s cognitive abilities. For instance, the level of risk can affect the user’s ability to perceive the objects in the environment (i.e., situation awareness).
- The decision makers’ cognitive abilities *determine* the possible user activities which can be performed. For instance, much risk leads to high stress for the user, thus, the decision maker could thereby reason in a different way. In other word, this affects which activities the decision maker performs.
- The decision maker *utilises* the interface in order to perform various activities, e.g., by passively or actively interacting with the interface.
- The interface needs to *reflect* the functionalities provided by the IF decision support.
- It must also be remembered that IF systems *capture* limited aspects of the environment (e.g., a collection of sensors captures movement of objects in the environment, and these sensors could have a limited view due to weather conditions), and so on.
The interaction outlined above is not straightforward as previously discussed. Typically, there are a number of bottlenecks along this circular relationship which can interfere and make the interaction, for instance, slow and unpredictable. For further details on the different elements of model, the reader is referred to Nilsson, Riveiro, & Ziemke (2008).

### 3.5 Reflective Summary

Despite the fact that it has been argued that the effectiveness of the overall IF process is affected by the utilisation of HCI (Hall & Llinas, 2001), there are limited studies of the decision maker in the IF community, that is, how IF systems actually support decision-making. Further, those that do exist provide encouraging research, for example, Bisantz et al., (1999), Blasch and Plano (2003; 2002), and Hall et al., (2007). It has, for example, been shown that users can be an active part of these IF processes and even play a prominent role in the fusion process (Blasch & Plano, 2002; Chan et al., 2005). Aspects which have been highlighted, thus far, are different cognitive process limitations (Blasch & Plano, 2002), trust issues (Bisantz et al., 1999), and HCI issues (Blasch, 2006; Hall & McMullen, 2004; Hall, Hall, & Tate, 2000). However, most often, the research inevitably ends up in some sort of independent, prototype specific user study (e.g., Brenton, Paradis, & Roy, (2002), and Irvine (2003)). An exception is a recent study by Hall et al., (2007) which theoretically compared and contrasted the IF process (JDL model) and general decision-making processes.

Despite these recent studies, no clear overall picture of user interaction and how such systems support decision-making have yet emerged from the IF community. In other words, what is evident in the research is that IF has not been approached from a decision maker’s point of view. However, in this chapter we have seen that it is indeed possible to describe IF systems in a decision-making context. Indeed, the chapter particularly highlights the importance of viewing IF systems as essentially decision support system if the aim is to better understand the interaction between the decision maker and the system itself. Such an exploration can be considered as the first step towards understanding the interaction between decision makers and IF technology in a human decision-making context. However, we still need knowledge about how decision makers interact with such systems at a detailed level. As a consequence, the next chapter investigates different possibilities of studying the interaction between a decision maker and semi-automated IF processes in a decision-making context.
CHAPTER 4

Understanding Interaction

Due to the methodological focus and contributions of the thesis, this chapter presents a literature review of current approaches within IF aimed at understanding the interaction and utilisation of IF technology. It also outlines an investigation of possible alternative methods used to capture interactions within complex systems from the area of Human Factors. In particular, this exploration can be seen as the first step towards identifying how one can best capture interactions between decision makers and technology in semi-automated IF processes.

4.1 Current Approaches within IF

The reviewed methods have not only been chosen for their ability to provide knowledge regarding the interaction from a user perspective, but also due to their representativeness in the IF domain.

Experiments

Many of the experiments reported within IF concern image fusion in particular, e.g., Irvine, (2003); Krebs & Sinai, (2002); and Muller & Narayanan (2009). Researchers have for instance been interested in questions such as the difference between using colour fused images compared to greyscale fused images, the effect of target identification using fused images, and users’ preference of fused or not fused images (Muller, 2006). In the study by Irvine (2003) decision makers’ attention were tested. In particular, fused verses non fused images and guiding cues were tested. Krebs and Sinai (2002) highlight that some experiments testing the effect of image fusion have improved performance while others have had less success. For instance, the authors showed that image fusion only improved tasks such as spatial orientation analysis and scene identification (Krebs & Sinai, 2002). In addition, Hall, Hellar, McNeese, Panulla, and Shumaker (2009)
propose a more general framework to evaluate what they call “human centred fusion artefacts”, in which real world problems can be connected with experiment producing data that can be analysed with statistical methods. They have created a laboratory including a simulation environment (NeoCITIES) in which experiments can be performed. By letting participants interact and respond to a situation display (including a map display, information about received reports, and information about available resources to deploy), they are able to study specific responses to emerging situations. In particular, their experiments include dynamic resource allocation, advanced visualization (e.g., 3D visualisation of decision space), distributed ad hoc analysis and decision-making.

In general, performing experiments involves constraining the environment to a laboratory setting. This in turn involves predefining variables, hypotheses and possible factors affecting the environment of interest. The danger is therefore that laboratory studies do not capture the real behaviour (see, e.g., Muller (2006) which, amongst others, highlights conflicting results when studying similar tasks in laboratory settings). Also, one cannot be able to predict all possible future situations. In this thesis, we are interested in capturing interaction which emerges in the context of use, that is, interaction which is heavily influenced and affected by the environment. The implication is that we do not know a priori all factors affecting this interaction. Moreover, most experiments study a cognitive ability in isolation from others, and not the interaction, per se, which we are interested in here.

**Task Analysis**

Task analysis has received increasing, though limited, recognition within the IF community. Blasch (2006; 2008), for instance, puts cognitive task analysis forward as a method to use in the context of IF. This method focuses on the cognitive abilities of the user rather than the order of the activities performed. Kettani and Roy (2000) also promote cognitive task analysis due to its ability to identify critical information which should be available to the decision maker. Salerno (2002) further explained that cognitive task analysis “provided us with some interesting insights of how OROs mentally visualize their environment in order to assess their situation” (p. 3). The advantages of Cognitive task analysis for IF are further reinforced by the method being included in one recent IF handbook, see Bossé et al., (2007). Another task analysis is **Goal Directed task Analysis** which has been used to inform IF design (Jones, Connors, & Endsley, 2009). This type of task analysis can be seen as a form of Cognitive Task Analysis. However, it should be noted that these techniques are not all commonly reported upon in the IF domain.

In general, performing a task analysis provides the researcher with information regarding how a task is carried out. Some variants of task analysis
focus on the task in particular while others also consider the cognitive abilities of the humans. That is, the focus of the method is not necessarily on how the user applies the properties of the tools to support his decision-making process, which is what we are concerned with in this thesis. Also, how the different elements interact in order to support a decision-making activity is not emphasised.

**Theoretical Assessment**

An alternative to empirical investigations, such as those discussed above, is using different existing theories and theoretically explaining the occurrence of different phenomena within a specific domain (for instance, the IF domain). Blasch and Plano (2003), for instance, used a leadership analogy to explain the relationship between a user and a machine in the context of sensor management (cf. Figure 4.1). One result was a taxonomy displaying whether or not sensor management is “user dominant” or “machine dominant” (cf. function allocation). A system can be user dominant when the user tells the system what to do; there is no freedom for automation. Machine dominant, on the other hand, means the “sensor manager” (similar to process refinement, level 4 in the JDL model) makes decisions based on available information (fully automated).

![Figure 4.1 Automation continuum (Blasch, 2003).](image)

These extremes actually define a scale and a system can be anywhere between them. More specifically, the model consists of specific attributes which can indicate level of dominance. The users can initiate (the task to be performed), delegate (specific tasks to the system) or consider the result from the IF system in their decision-making processes. Also, the interaction can be classified as -
authority} (users have authority over the IF system), -interactive (the task is divided) or -submissive (the user is submissive and obeys the system). Furthermore, the interaction can, for instance, be classified as task–user–monitor oriented, depending on whether the role of the user is to monitor the system or to use the system for accomplishing specific activities.

In general, this taxonomy does not provide a detailed characterisation of the interaction. For instance, the taxonomy only considers the sensor management part of the IF process. Moreover, the taxonomy does not capture the dynamic nature of interaction (as the dominance of interaction most often changes over time), but it is this aspect that is of interest in the thesis. Hence, although this model can provide a starting point, empirical research is required to understand the nature of interaction within semi-automated fusion processes. It should also be noted that this model has not received general use within the IF community.

**Additional Approaches in IF**

More recently, the Task/human/technology Triad Model (Paradis, Brenton & Roy, 1999) was developed. The model represents the relationship between the technology (the system designers who need to develop the technology) and humans (human factors specialists have knowledge about the limitations/capabilities of users), as well as the task which needs to be accomplished. The model thus intends to facilitate the development of command and control systems built on data fusion technology. It was created due to a typical lack of cognitive fit in IF systems design, that is, “[t]here is a tight link between this mental model used to structure and express situation elements and the cognitive process involved in achieving the levels of awareness. This link is known as the cognitive fit and requires an understanding of how human perceives a task, what processes are involved, what are the human needs and what part of the task can be automated or supported” (Paradis, Brenton & Roy, 1999, p. 3).

Hence, the triad model emphasises the relationship between users, the task to be performed and the technology executing the task. An important aspect of the model is that it specifies when to develop requirements.

Although it has the potential to be a good tool when developing new IF systems, it does not detail the actual interaction between the decision maker and the IF system in the final product since it was developed to be used as a system development process. That is, there is no emphasis on how to describe the interaction, which is of interest in this thesis.

The characteristics of the above reviewed approaches are presented and contrasted in Table 4.1, in which one can see that the methods involve either micro (i.e., defined set of sensors in a constrained environment) or macro level
analysis (i.e., full scale system involving many users and systems). In addition, they differ in terms of what is being produced. Generally, one can argue that methods such as these would not provide the level of detail which is required to capture interaction in semi-automated fusion processes. The following sections thus investigate approaches used within other disciplines to determine if they can produce what is required in this thesis.

Table 4.1 Methods found within the IF domain

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<th>Current methods in IF</th>
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<th>Experiments</th>
<th>Usability test</th>
<th>Theoretical assessment</th>
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</thead>
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<tr>
<td>Domains</td>
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<td>Health care, Defence, Image fusion</td>
<td>Defence</td>
<td>Defence</td>
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<td>Micro</td>
<td>Micro</td>
<td>Micro</td>
</tr>
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<td>Study object</td>
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<td>Prototypes, simulations</td>
<td>Prototypes, simulations</td>
<td>existing systems</td>
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<tr>
<td>Issue investigated</td>
<td>Cognitive process</td>
<td>System properties, cognitive process</td>
<td>System properties</td>
<td>System properties</td>
</tr>
<tr>
<td>Focus</td>
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<td>Empirical: Laboratory with users</td>
<td>Empirical: Laboratory with users</td>
<td>Analytical: Expert judgment</td>
</tr>
<tr>
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<td>Descriptions, models,</td>
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<tr>
<td>Focus</td>
<td>Describing</td>
<td>Evaluating</td>
<td>Evaluating</td>
<td>Understanding</td>
</tr>
</tbody>
</table>

4.2 Methods for Studying Human Decision Making

Since the interaction we are interested in exists within a decision-making context, it is worthwhile to examine how human decision-making can be captured. Rational decision-making, also referred to as classical decision-making, characterises the early theories which focus on how one can reach an optimal decision by calculating, for example, probabilities of alternatives (among others, subjective expected utility theory, multi-attribute utility and Bayes’ theorem (Edwards & Fasolo, 2001). However, the decisions that human decision makers actually make are often not in line with rational decision making theories due to the fact that there are often other, uncountable, factors which influence our decisions in real world settings. These limitations have been recognised and as a response, Naturalistic Decision Making (NDM) (Zsambok & Klein, 1997), focusing on real world decisions made by experts, has emerged.

In addition to the many models within NDM explaining expert decision-making (e.g., recognition primed decision model, imagery, decision latter, etc.
(Zsambok & Klein, 1997)), specific methods have been developed to study decision-making. However, it should be noted that most of them do not involve the capture of decision-making specifically supported by technology. Even the decision support system domain does not feature many field studies reporting on the relationship between decision support systems and human decision-making theories (cf. the International Journal of Decision Support Systems). The focus is, rather, on performing evaluations in terms of performance criteria such as satisfaction and outcome. Similarly, within the HCI domain, there has not been a great level of attention to human decision-making. As Hutchins, Morrison, and Kelly (1996, p. 7) argue: “the vast majority of research on human-computer interaction design has been devoted to characteristics of displays that impact human perception, such as symbol legibility or detectability, and on relatively simple cognitive functions such as memory tasks. Fewer efforts have been devoted to understanding the effects of the format and manner in which information is presented on more complex levels of human cognition such as decision making”.

However, there are methods used for capturing human decision-making. One of the most well-known methods emerging from the NDM research which can be used for elicitation of expert knowledge is the Critical Decision Method (Klein et al., 1989). The method views decision-making as captured by the Recognition Primed Decision Making (RPD) Model (Klein, 1998) which emphasises the importance of domain knowledge and previous experience in making decisions. The model is characterised by dealing with decisions made under high stress and time pressure. The concept of the model is that when experts encounter a new situation which demands a decision, they use their previous experience in order to solve the current situation. In other words, rather than choosing among alternatives, decision makers assess the situation and select the most appropriate decision. This process is divided into three main parts: situation recognition (the situation is classified as either typical or new and the decision maker identifies (recognises) distinguishing cues which are crucial for the situation), serial option evaluation (different alternatives are evaluated sequentially, with the most typical action first, i.e., an action queue, until a satisfactory alternative is reached), and mental simulation (on order to determine whether an alternative is satisfactory or not, the decision maker acts it out in the mind using the imagination, i.e., a mental stimulation).

The actual method builds upon a retrospective interview strategy. The focus of the interview is to capture the decision-making process related to a recalled incident representing a non-routine case. The method includes a set of specific probes which helps the researcher capture relevant aspects of the decision process. Probes were tailored for capturing cues, knowledge, analogues, goals, options, basis, experience aiding, time pressure, situation assessment, and hypotheticals.
The process of the method is as follows: select incident, obtain unstructured incident account, construct incident timeline, and identify decision point.

In general, the method focuses largely on the decision-making process of one particular individual. Hence, this method would not capture human-technology interaction in the way that is of interest in the thesis, due to the lack of focus on how tools are manipulated in the support of the decision-making process. In addition, the method has an implicit focus on decision-making as a solely internal human process.

### 4.3 Methods for Studying Complex Systems

Human Factors have a long tradition of capturing interaction within complex systems involving both technology and humans (also referred to as socio-technical systems). In an IF setting, one can consider the decision maker and the IF technology as such a complex system. It is therefore worthwhile to investigate their approaches of capturing interaction. The number of methods typically used within the discipline is actually rather large. Stanton et al., (2005), for instance, review 91 of them. All the methods have different focuses and, hence, not all of them capture interaction in the way that interests us in this thesis. In the review of methods below, we focus foremost on methodologies involving complex (socio-technical) systems. These methods should be viewed in contrast to typical information systems modelling methodologies (Siau & Wang, 2007) which do not typically involve ways of capturing human cognitive abilities.

In particular, cognitive system engineering (CSE) is an interesting framework as it concerns the analysis, design and evaluation of complex socio-technical systems. In practise, “CSE is concerned with how human-machine coagency can best be described and understood” (Hollnagel & Woods, 2005). More specifically, “the agenda of CSE is how we can design joint cognitive system so that they can effectively control the situation where they have to function” (Hollnagel & Woods, 2005, p. 24). The underlying principle of CSE is that “cognition is distributed rather than isolated in the mind of a thoughtful individual, and cooperation and coordination are ubiquitous. Operators are embedded in larger groups and organisations, which together define the conditions for work, the constraints and as well as resources” (Hollnagel & Woods, 2005, p. 37)\(^\text{11}\). That is, the focus is on what the joint cognitive system do (and why) with the goal to improve design.

\(^\text{11}\) This view is consistent with the DCog approach (cf. Chapter 5). However, “Semantically, the main difference between ‘cognition in the mind’ and ‘cognition in the wild’ relates to how cognition should be studied. From a CSE perspective, the question is whether one should study cognition \textit{per se} at all, the alternative being to study the performance of the JCS [joint cognitive system] ... In CSE, human cognition is no longer the central issue, regardless of whether it is
One of the most prominent work within this discipline thus regards cognitive work analysis (Rasmussen et al., 1994; Vicente, 1999) which is a broad framework including the design, development and analysis of complex systems (Roth, Patterson, & Mumaw, 2002). More specifically, the underlying assumption of cognitive work analysis is that complex (socio-technical) systems are dynamic with changing goals, work procedures and unanticipated events. Hence, the focus of the framework is on defining the boundary of the system (i.e., the objectives, work requirements, and the resources) rather than a trajectory of task procedures within the system. That is, the framework views the system as a closed-loop, adaptive system (Naikar, Hopcroft, & Moylan, 2005; Rasmussen et al., 1994). To define the boundary of the system, the cognitive work analysis consists of five phases (Kilgore, St-Cyr & Jamieson, 2009):

- Work domain analysis
- Control task analysis
- Strategies analysis
- Social organisation and cooperation analysis
- Worker competencies analysis

The framework relies on interviews with users, field studies (i.e., observations of activities), walkthrough analyses, and reviews of documentation (e.g., standard operating procedures) as data collection methods (Stanton et al., 2005). The main purpose of the different phases is to decompose the analysed work system in terms of its elements, e.g., goals, functions, tasks, actors and their skills and cognitive properties (cf. Table 4.2). Nevertheless, the approach is flexible as it is argued that the methods in the different phases should be viewed as a toolkit, and can be used individually or in cooperation depending on the nature of the investigation (Stanton et al., 2005). A contributing factor to this flexibility can be the loosely defined methods and phases (cf. Burns, Bisantz, & Roth, 2004) for examples of different work domain analyses), however, this can also make the framework difficult to use. More recent publications (Kilgore et al., 2009; Stanton et al., 2005) thus provide a more detailed description of how to apply the framework. That the methodology is appreciated is evident in the many recent studies utilising the framework (cf. Bisantz & Burns, 2009), it is however, criticised for being complex and time consuming.
Table 4.2 Overview of cognitive work analysis, including methods, techniques and necessary products (adapted from (Naikar, Hopcroft, & Moylan, 2005)

<table>
<thead>
<tr>
<th>Phases of CWA</th>
<th>Kinds of information</th>
<th>Modelling tools</th>
<th>Type of boundary or constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work domain analysis</td>
<td>Purpose and stricter of work domain</td>
<td>Abstraction-decomposition space</td>
<td>Purpose, values and priorities, functions, and physical resources</td>
</tr>
<tr>
<td>Control task analysis</td>
<td>Goals to be satisfied, decisions/cognitive processing required</td>
<td>Decision ladder templates</td>
<td>Activity in terms of work situations, work functions and control tasks</td>
</tr>
<tr>
<td>Strategies analysis</td>
<td>Ways that control tasks can be executed</td>
<td>Information flow maps</td>
<td>Strategies for carrying out activity</td>
</tr>
<tr>
<td>Social organisation and cooperation analysis</td>
<td>Who carries out work and how it is shared</td>
<td>Annotations on all the above</td>
<td>Distribution of work including allocation of work to individuals; organisation of individuals into teams; and communication requirements</td>
</tr>
<tr>
<td>Competencies analysis</td>
<td>Kinds of mental processing supported</td>
<td>Skill, rules and knowledge models</td>
<td>Perceptual and cognitive capabilities of workers</td>
</tr>
</tbody>
</table>

Considering that the aim of this thesis is capturing the interaction and interdependencies within semi-automated fusion processes in a decision-making context, the social organisation and cooperation analysis (phase 4) could be of interest. Such an analysis aims to identify how tasks are distributed between humans and technology within the work system (Stanton et al., 2005). The analysis is based on the abstraction-decomposition space, decision ladder templates, and the information flow maps. In particular, the value of the information flow maps is emphasised, as they can be enhanced to visualise computer, human and shared activities (Kilgore et al., 2009). Furthermore, to capture decision-making activities the strategies analysis (phase 3) could be of interest. The main aim of this phase is to capture how tasks are performed. Here, information flow maps can illustrate the information processing activities and knowledge states required to perform a specific task. However, it is apparent that each phase has its particular purpose and it can be difficult to capture the intersection of (and thus the relationship between) the phases. For the purpose of this thesis, however, capturing interaction in semi-automated processes would ideally require information on the relationship between the decision-making strategy and the fusion process. Hence, although relevant in general terms, this framework would not serve the specific purposes which are the aim for in this thesis (illustrate the complexity of the information fusion process and the active role of users and the interrelationship between human decision-making and the fusion process).
4.4 Methods for Studying Automated Systems

Nowadays, automation is often a large part of complex (socio-technical) systems. Automation refers to “the full or partial replacement of a function previously carried out by the human operator” (Parasuraman, Sheridan, & Wickens, 2000, p. 278). More specifically, a 10 level scale of automation can be identified ranging from 1: the computer offers no assistance and the human must take all decisions and actions to 10: the computer decides everything, acts autonomously, effectively ignoring the human (Parasuraman et al., 2000). Automation can, for instance, be used in the area of information acquisition, information analysis, decision and action selection, and action implementation (Parasuraman et al., 2000). Automation is a complex issue, it is not always the case that an increase of automation will lead to better systems (consider for instance skill degradation, loss of situation awareness, etc. (Parasuraman et al., 2000)).

There are several different methods which can be used to understand the nature of automation and, in some cases, increase it. General methods include theoretical analyses, laboratory experiments, simulation and modelling, field studies and analysis of real-world incidents and accidents (Parasuraman et al., 2000). In addition, specific methods such as the function allocation method (Wright, Dearden, & Fields, 2000; Boy, 1998) have been developed. In simple terms, the function allocation analysis can be described as a method which can be used to “determine whether jobs, tasks, system functions etc., are allocated to human or technological agents within a particular system” (Stanton et al., 2005, p. 483). Functional allocation has been widely used (e.g., Boy, (1998); Wright et al., (2000)). The basic idea behind the analysis is to consider, for each task, the benefits or disadvantages of having it performed by either the machine or the human. The analysis builds upon a hierarchical task analysis (previously described), in which each bottom task is considered for human or machine performance. In practice, this approach could be used to determine human and machine performed tasks within a semi-automated fusion process. However, it would not provide information regarding the actual interaction within the process, as is of interest in this thesis.

4.5 Reflective Summary

There are a number of possible approaches to create a base from which a detailed model of the interaction between humans and technology within an IF context can be extracted. However, from the perspective of this thesis, none of the methods mentioned here are without problems. Common to all of them is a focus on capturing the system from a human individual perspective, with no natural way of capturing technological aspects within the same language/frame. More
specifically, one can argue that traditional task analysis, for instance, does not take into account a team of individuals working together, collaboratively. This limitation has also been noticed by Zachary, Ryder, & Hicinbothom (2000), who develop their own adaptation of the method, COGNET (cognition as a set of task networks). Similarly, hierarchical task analysis (Kirwan & Ainsworth, 1992) does not take into account the design of the artefact and in what way it supports the task. The task is effectively treated in isolation from the technology used. In contrast, there has been a recent development of different variants of cognitive work analysis (Rasmussen et al., 1994; Vicente, 1999) which include a broader perspective, taking into account the surrounding environment. However, one can still argue that the actual interaction between different parts of the system has only been captured to a limited extent. Also, the tools humans actually use in carrying out various tasks have not been appropriately accounted for.

To conclude, it would therefore be difficult to capture the interaction, that is of interest to this thesis, with the traditional approaches. Consequently, there is a need to compliment the traditional methodologies. The next chapter explores the possibilities of such a complement through the incorporation of concepts and methodologies from DCog (Hutchins, 1995a).
This chapter discusses the theoretical framework of DCog. An explanation of the theory is followed by a focus on how DCog has been used to inform other disciplines, such as Human-Computer Interaction and Medical Informatics. The implications of a DCog perspective on IF are also considered. Additionally, current attempts at transforming DCog into a more structured method for studying human-technology interaction are investigated. The review in this chapter can therefore be considered the first step in exploring the abilities of DCog to capture interactions between decision makers and semi-automated IF processes in a decision-making context, which is addressed in more detail in later chapters.

5.1 Central Theoretical Principles

DCog emerged as a theory during the 1980s and was manifested by Hutchins in his book “Cognition in the wild” (Hutchins, 1995a). Since then, it has been established as a research discipline and lately received renewed attention, as it has evolved outside the domain of Cognitive Science to other application areas, which is included later in this chapter\(^\text{12}\). Cognitive science focused on studying human cognition simply in terms of a single individual’s internal processes (e.g., Miller, 1956). In other words, there was a rather narrow definition of what constitutes human cognition, since nothing “outside” the individual was traditionally taken into account. That is, DCog distinguishes itself from other approaches to cognition in terms of the boundary of analysis and the mechanism which is

\(^{\text{12}}\) It should be noted that DCog as a theoretical framework for the explanation of cognition is still very much a matter of debate (Perry, 2003). See, for example, the discussion between Halverson (2002) and Nardi (2002), as well as Nardi (1996).
believed to be included in cognitive processes\textsuperscript{13} (Hutchins, 2001). Its commitment to “computation” also sets it apart (Hutchins, 2001). More specifically, the following underlying central theoretical principles of DCog can be extracted (Hutchins, 2001):

- Complex intelligent phenomena (i.e., cognitive processes) emerge from interactions among elements in complex systems.
- A complex system (referred to as “cognitive system”) is distributed, e.g.,
  - across the members of a social group
  - between internal and external (material or environmental) structures
  - over time (in which earlier events shape the latter).
- A complex system can be understood by studying the dynamic flow of information in terms of the propagation and transformation of representational states between elements within the cognitive system.

In general, the above stated principles can be found in work explaining the basics of DCog (e.g., Moore & Rocklin (1998); Perry (2003); Rogers (1997); Salomon (1993); Sutton (2006)). These principles can seem simplistic but their implications, some of which are listed below, are fundamental (Hutchins, 1995a, 2001):

- High-level human cognition, in Hutchins’ view, depends on the interaction with the material and social world.
- Cognitive processes involve the manipulation (including propagation, transformation) of representational states which are distributed across individuals and artefacts, between (human) internal structures and external ones, and over time. Hence, cognitive processes cannot be disconnected from the cultural and social phenomena (as they are part of the cognitive system), leading to the requirement to study these phenomena as they exist in real settings.
- In real settings one studies interactions both between, and within, the physical, social and conceptual space. Hence, coordination is thus a very important concept.
- The boundary of the individual is extended to a larger unit of analysis (socio-technical unit), thus some cognitive processes are observable, since they are no longer “hidden” inside individuals.
- The cognitive properties of the interaction within cognitive systems, i.e., the collective behaviour, can be captured.

\textsuperscript{13} A cognitive process, in this context, is for instance, processes involved in memory, decision making, inference, reasoning, learning, and so on (Hutchins, 2001).
Due to the computational heritage, the cognitive process can be characterised in terms of the propagation and transformation of representations, since the same language is used to explain processes occurring in humans and artefacts (technology)\(^1\).

An outside-in approach is used to explain cognitive processes which consequently imply that one can explain the inside by looking at the outside. The explanation does not start from the brain, it starts from the cultural environment.

A stable underlying structure can be identifiable (goals and activity) (Nathanael, Marmaras, Papantoniou, & Zarboutis, 2002).

In summary, Hutchins (1995a) considers that human cognition is *constituted* in the interactions of brain and body with the material and social world (sometimes referred to as “Strong DCog” (Hutchins, 2009)). However, over the years, the work initiated by (Hutchins, 1995a) has developed, and today, one can also distinguish a weaker interpretation of DCog (sometimes referred to as “weak DCog” (Hutchins, 2009)). This line of research merely acknowledges that cognition is *affected or shaped* by the interactions with the material and social world. That is, researchers belonging to “Weak DCog” would not agree with statements that, for example, high-level human cognition *depends on* the interaction with the material and social world. Another difference among groups within DCog is the way they choose to study DCog. Hutchins (Hutchins, 1995a) has his grounding in anthropology, and hence, emphasises the importance of studying cognition in real settings, studying “cognition in the wild”. More specifically, Hutchins views DCog as a theory of cognition in which cognitive ethnography is the method of use. In contrast to this, for instance, one can find researchers (Norman, 1993; Zhang, 2000) who usually prefer laboratory based studies to investigate DCog. In other words, they typically focus on the interaction between one single human and one artefact (i.e., the exchange between internal and external structures) to learn about DCog. Interestingly, the latter approach could be traced back to how problems are traditionally approached within psychology.

In this thesis we are interested in applying the underlying concept of DCog, as introduced by Hutchins (1995a), see bullet list above.

\(^{1}\) This is by no means an attempt to equalise humans and technology (Halverson, 2002).
Chapter 5 Distributed Cognition

5.2 Terminology

In DCog, explicit definitions of the concepts used are rare. However, with Hutchins (1995a) as a starting point together with examples of DCog studies, this section provides a synthesised view of the most characterising concepts of DCog. In addition, explicit definitions of the concepts can be seen as a necessary step for the introduction of the framework in new domains (Moore & Rocklin, 1998). More specifically, the following concepts are defined for this thesis: unit of analysis, entity, representational states, information propagation, transformations, and mediation. These concepts have been chosen because they represent the ones most typically used when performing a DCog analysis.

Unit of Analysis

The unit of analysis determines the boundary of the analysis, i.e., what to include in the analysis. The central concept within DCog is to capture phenomena as they are distributed over humans and artefacts within a system. This system can be referred to as a Functional System (Hutchins, 1995a; Rogers & Ellis, 1994), Cognitive System (Cohen et al., 2006; Galliers et al., 2007; Hollan, Hutchins, & Kirsh, 2000; Nemeth, Cook, O’Connor, & Klock, 2004; Perry, 1998), Socio-Technical System (Cox, Sharples, Stedmon, & Wilson, 2007; Hutchins, 1995a, 1995b), Activity System (Hazlehurst et al., 2007) or just the word System (Fields et al., 1998; Horsky, Kaufman, Oppenheim, & Patel, 2003).

For instance, Fields et al., (1998, p. 2) refer to the unit of analysis as being “a system of individuals and external representational artefacts, carrying out some activity”. Similarly, Hazlehurst et al., (2007, p. 539) refer to it as “the activity system comprised of actors and tools, together with rules and understandings that guide interactions in a structured environment or workspace”, while Cox et al., (2007, p. 428) argue “[t]he unit of analysis is the socio-technical system, made up of individuals and artefacts”. Likewise, “a cognitive system consists of people working together, and the artefacts they use” (Susi & Ziemke, 2001, p. 284). Another description is provided by Rogers and Ellis (1994, p. 124): “The central unit of analysis is the functional system, which essentially is a collection of individuals and artefacts and their relations to each other in a particular work practice”. That is, irrespective of the word used and level of details provided, researchers refer to the same underlying core.

Thus, in this thesis, the unit of analysis is the socio-technical system (including both humans and artefacts involved in the process (activities) to achieve a goal). More specifically, the unit of analysis is delimited by the functional relationships between entities, in which representational states of information are transformed. These concepts are explained in more detail in the following sections.
Entities
The phenomena of interest are considered to be distributed across different entities within the system (also denoted as agents (Artman & Waern, 1999; Ferruzca et al., 2007; Perry, 2009), elements (Alač & Hutchins, 2004; Hollan et al., 2000; Morgan, Brickell, & Harper, 2008), components (Cohen et al., 2006; Galliers et al., 2007; McMaster, Barber, & Houghton, 2006), or only by their name, humans and artefacts (or external structures) (Artman & Waern, 1999; Fields et al., 1998). What is specific for DCog is that entities thus refer to both humans and artefacts. As both humans and artefacts are “entities”, it might imply they are equal, but artefacts are not considered (biologically) cognitive (Halverson, 2002). That is, “[a] process is not cognitive simply because it happens in the brain, nor is a process noncognitive simply because it happens in the interactions among many brains” (Hollan et al., 2000, p. 175).

In this thesis, entity is defined as a specific information resource (not limited to a specific physical artefact). That is, a computer includes different information resources, such as, email and internet, which possess different properties, and so on. A human entity is a human information resource that plays a functional role within an activity (involved in the fusion process). In this thesis, we distinguish between human and artefact entities due to the nature of the IF domain, that is, we want to have the ability to emphasise that humans are an important part of the fusion process.

Representational States
From a Hutchins (1995a) point of view, representational states are the primary analysis unit when visualising the processes within the system of interest. Representations are important because “[t]he form of a representation can influence and sometimes determine what information can be easily perceived, what processes are activated, what can be derived from the representation” (Rinkus et al., 2005, p. 6). It is further argued that representations are a more “manageable unit of examination” compared to the term “information” (Perry, 1998). Examples of studies using representational states to learn about the characteristics of a system includes: Artman & Garbis, (1998), Hazlehurst, Gorman, & McMullen (2008), Hollan et al., (2000), Hutchins (1995a), and Perry, (1998).

A representational state, in these studies, is defined to different degrees. Some only use the word representation (Galliers et al., 2007) without a specific definition. Other researchers are a little more specific and distinguish between internal and external representations (Cox et al., 2007). Even the word public

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15 It should be noted that Artman & Waern, (1999) and Perry (2010) only refers to humans as agents.
representations have been used (Artman & Garbis, 1998). There are only a few researchers who explicitly define representational states. For instance, Hazlehurst et al., (2008, p. 228) use the following definition: “a representational state is a particular configuration of an information-bearing structure, such as a monitor display, a verbal utterance, or a printed label, that plays some functional role within a process”... “Representational states are particular configurations of physical media (e.g., verbal utterances, pen marks on a form, patterns on a display device, or the position of a control knob on a heart-lung machine) that can model the properties of other objects or events when engaged by interpretive processes”.

In this thesis, representational state is thus defined as knowledge and information represented at specific instances in the conduct of an activity.

**Information Trajectories**

In order to learn about the information trajectories and the characteristics of the system you examine the propagation of representational states (i.e., “how representations are transformed and propagated in the performance of tasks” (Hutchins, 1995b)). That is, the system’s processes propagate representations across the diverse set of entities in the conduct of activities changing representational states (Hazlehurst et al., 2008). The carrier for representational states is not only entities, such as humans or artefacts, but also (virtual) structures, such as work procedures, and so on. That is, as propagated, the representational states can have the format of mental (internal), external (visual, auditory), social and technological representational states (Rogers & Ellis, 1994).

In this thesis, information propagation refers to the flow of information during which representational states transform (e.g., visual, mental and auditory) when propagated between entities in the conduct of an activity.

**Mediation**

The entities of the system mediate the properties of the system. For example, in the study by Cox et al., (2007) it is highlighted that communication can be mediated by artefacts. This is in line with Hazlehurst et al., (2007) who identify specific tools used in heart surgery, which mediate, e.g., communication or manipulation of the heart. Interestingly, Fields et al., (1998) explain that communications itself can mediate control. That is, all entities (including physical and virtual (e.g., work procedures, etc.) artefacts and humans) can have mediating properties. However, as Hutchins (1995b) points out: “[t]he properties of functional systems that are mediated by external representations differ from those that rely exclusively on internal representations, and may depend on the physical properties of the external representational media. Such factors as the endurance of a representation, the sensory modality via which it is accessed, its
vulnerability to disruption, and the competition for modality specific resources may all influence the cognitive properties of such a system” (p. 286).

In this thesis, mediation refers to the mediating role of humans and artefacts in the propagation of representations, a process denoted by the functional relationship between the entities. Learning about the fusion process is of particular interest for this thesis.

5.3 Understanding Emergent Phenomena in Different Disciplines

DCog has been used successfully in Cognitive Science to shed light on various human cognitive processes. In recent years, DCog has even gained increasing recognition outside mainstream cognitive science and been adopted by other domains. The following sections elaborate on these points.

5.3.1 Cognitive Science

DCog emerged within Cognitive Science which is interested in understanding human cognitive processes. Using a DCog perspective has different implications for how these processes are portrayed. For instance, one consequence is that intelligence is manifested at a system level rather than an individual cognitive level (Hutchins, 1995a; Norman, 1993). Consider the mathematical problem previously mentioned. In order to solve an equation, it transpires that, in addition to pen and paper to follow the mathematical steps, there is a need to obtain help from another individual to clarify the problem. Solving the problem thus not only requires the perception and thought processes of two persons, but also the use of a tool (paper) to extend an individual's memory. Therefore, the intelligence is distributed in terms of setting up the problem in collaboration with another person and in performing manipulation/mathematical procedures, both in one's head and by writing down resulting partial answers. Hence, it is distributed both between people, as well as a person and an object (Norman, 1993). This way, intelligence is portrayed as an emergent quality rather than a “possession” (Salomon, 1993).

Thus, coordination is the main concern of DC. This is in contrast to traditional cognitive science which does not need to consider coordination to the same extent. Traditionally, external representations are only considered as input stimuli (thus, the reasoning is in terms of, e.g., applying condition-action rules to propositional representations of a situation) (Liu et al., 2008). One example of coordination is the study by Hutchins (1995a) which explains navigation as an information processing activity, where the information processing is not characterised in terms of individual cognition, but rather as an emergent process of the coordinated activities of the crew (Perry, 2003). More specifically, it is
shown that the activity emerges from naval regulations, the standardised training of the crew, practices that are local to the vessel itself, and constrains of the technology used. To navigate is a combined effort of the collaborating individuals. Hence, from a DCog perspective, navigation is not an achievement of one single individual.

Typically Situation Awareness is portrayed as a property of an individual (cf. (Endsley, 1995), i.e., one perceives facts and through mental manipulations of these facts, one comprehends and predicts future states of the environment. In contrast, a study by Hazlehurst et al., (2007), suggests that situation awareness emerges through the coordinated behaviour of the activity systems. More specifically, the communication patterns between the individuals function as a coordination device to: “(1) directly determine the current state of the system (direction), (2) reflect and create understandings of the current state of the system (status, alert, explanation), (3) establish expectations about future states of the system (goal-sharing, problem-solving)” (Hazlehurst et al., 2007, p. 11). Although, it should be noted that the study was limited to verbal communication, and thus the role of artefacts for achieving situation awareness was not examined.

A DCog perspective also has an impact on how cognitive processes, such as memory, are portrayed. Traditional research regarding memory has concentrated on how we perceive and store information as an isolated mental process (Liu et al., 2008). This has, for instance, resulted in the determination of the limitation of working memory “the magical number 7±2” 16. Salomon (1993) explains: “… memory (like other psychological phenomena) changes profoundly in nature, appearance, and function when studied in its natural complexity, as contrasted with its study under highly controlled conditions” (p. xii). That is, from a DCog perspective, our memory is not an isolated process in the head. Instead one needs to account for the external stimuli which influence and become part of the process. Also the process is not static, it evolves over time.

The DCog perspective also has an impact on the process of learning and using a DCog perspective in education would have major impacts (Salomon, 1993). The implications for DCog can be exemplified by thinking of learning a multiplication table. According to Salomon (1993) one should “… place greater emphasis on access to tools to think with than on solo understanding without tools, on partnership rather that on the cultivation of in-the-head cognitions” p. xvii). That is, the focus is on reasoning with tools rather than without them (i.e., partnership in learning). A DCog view would also have an implication for groups of individuals learning something (Nickerson, 1993). Actually, there are two

16 This is a theory based on laboratory studies which imply that we can only hold about 7 plus minus 2 units in our working memory (see, e.g., Miller, 1956 or any Introductory cognitive Science book)
different approaches within educational learning, specifically, a “person-solo” (individual cognition) and “person-plus” (both person and its surroundings) (Salomon, 1993).

Interestingly, one can note that decision-making, as such (as in contrast to previous cognitive processes mentioned), has not yet been extensively studied in a DCog spirit (apart from theoretical assessment, e.g., Patel et al., (2002)). The following sections include an explanation of how DCog has been treated in other research disciplines, in particular, a presentation of the HCI and the Medical informatics domain.

5.3.2 Human Computer Interaction

HCI is a research discipline interested in the different aspects of the interaction between humans and computers. The discipline concerns the study, design, construction and implementation of human computer interaction. Within HCI, DCog is most often used as an analytical method with which to understand the underlying mechanism of the relationships between humans and computer, as well as make them explicit. It has been argued that a DCog perspective would influence all parts of the HCI development process, such as studying the phenomenon, recording the data, encoding the findings, analysing the result, and designing/redesigning applications (Halverson, 1994). It has also been argued that the DCog perspective would involve a commitment to performing ethnographic studies and controlled experiments in which the objects of study are the work materials and workplaces in use (Hollan et al., 2000). Hence, it involves a commitment to studying interaction in its context, that is, viewing the study object as embedded in an environmental and social structure.

In addition, DCog can provide new insights into common concepts within the domain. For instance, as the premises change for HCI in the light of new advancements in technology, there is a need for theories which can handle phenomena beyond the individual (e.g., group coordination). That is, the HCI domain has developed from concentrating on the interactions between a user and a single computer to involving multiple people working on networked computers as well as ubiquitous computing. In this context, it has been argued that a DCog perspective is necessary to allow for a better understanding of the emergent properties of the interaction. Indeed, Halverson (2002) has explored DCog as a theoretical foundation for CSCW studies. In particular, it is highlighted that DCog can provide the correct unit of analysis, since it emphasises the broader socio-cultural-systems which can be seen as a requirement when studying

17 CSCW can be seen as a specialised area within HCI which is interested in group work and how such work can be supported
collaboration between individuals mediated by artefacts (i.e., CSCW). Halverson (2002) also argued that its focus on the representational state can be useful for design as the approach can be seen as data driven.

More specifically, as the domain has developed, the human information processing paradigm, which HCI was originally founded upon, does not accommodate all the aspects of this new environment (Hollan et al., 2000). Hollan et al., (2000) indicates examples where DCog can provide a new perspective for HCI. For instance, it can enrich the possibilities of ‘direct manipulation’, a concept developed during the 1980s, according to which users should be able to directly manipulate objects and see the effect of their action (manipulation). The intention was to be able to use knowledge of the physical world in order to interact with the virtual world. For example, moving a document between two places in a computer operating system with a mouse can be performed in a way that is similar to a person moving a physical document between a desk and a folder. Direct manipulation has been developed from a traditional information processing paradigm which focuses on “symbols as tokens that refer to something other than themselves, but pays little attention to the strategies people may develop to exploit the physical properties of the representing tokens themselves” (Hollan et al., 2000). A DCog perspective, on the other hand, would not focus on how well the action mimics a physical action in the real world; instead, it would focus on the properties and possibilities of the token as well as the representation (Hollan et al., 2000). Referring to the example of moving a document in a windows environment, DCog would focus on the representation itself (e.g., can the icon representing the document be reduced, enlarged, etc.), how it is used and manipulated to coordinate the activity. This would also promote history-enriched digital objects as well as argue for spatial rather than temporal organisation.

Another reason for the interest in DCog by HCI researchers may very well lie in the fact that HCI researchers trained in cognitive science can use that knowledge and conceptual apparatus to understand DCog (i.e., the notion of information representation and representational transformations) (Perry, 2003). That is, DCog can be fairly easy to adopt, since most interested researchers already have knowledge of the basic units needed to understand and apply it.

The impact of DCog can be seen in the theoretical arguments put forward by, for example, Halverson (1994; 2002), Hollan et al., (2000), Liu et al., (2008), Rogers (2004), Rogers and Ellis (1994) (see above). The theoretical arguments are further manifested not only by the many DCog studies performed (e.g., Baber, Smith, Butler, Cross, and Hunter (2009); Baber, Smith, Cross, Hunter, and McMaster (2006); Burnett et al., (2009); Busby (2001); Morgan et al., (2008); Schrire (2004)) but also by the emergence of tailor made “DCog” methodologies, such as the resource model (Wright et al., 2000) and distributed cognitive
walkthrough (Eden, 2007; 2008) to be used within the community. This is further reinforced by DCog nowadays often being mentioned in various HCI handbooks, see, for instance, Benyon, Turner, & Turner (2005), Perry (2003), and Preece, Rogers, and Sharp, (2002), as a concept to be considered.

As DCog seeks to understand and explain the organisation of human cognitive processes by studying the tools humans interact with, DCog can also provide insights into the study of more complex human-computer interaction in work settings. In particular, DCog is argued to be a useful tool when analysing highly constrained situations (e.g., cockpit of an airplane, a navy bridge, etc.) (Nathanael et al., 2002). That is, it is useful in situations characterised by multiple agents and a rather stable transformation function. Studies include settings such as: aircraft cockpits (Hutchins, 1995b; Hutchins & Klausen, 1998), air traffic control rooms (Cox et al., 2007; Fields et al., 1998; Marti, 2000), navy ship bridge (Hutchins, 1995a), military command and control (McMaster et al., 2006; Walker et al., 2009), emergency coordination centres (Artman & Waern, 1999), and co-ordination of collaborative activities (Perry, 1998). In such studies, the focus has been on how artefacts and technology are used as cognitive resources as well as coordinator of activities. For instance, in a study by Marti (Marti, 2000), DC was used to inform the re-design of an air traffic control system, and resulted in a system which provided better support for the operators’ activities.

Interestingly, environments as the ones mentioned here have been referred to as socio-technical systems, emphasising the fact that humans and technology are one system together, thus maintaining the spirit of DCog.

5.3.3 Medical Informatics

The medical domain (i.e., Medical Informatics, Clinical Systems, and Health Care Systems) is another area which has recognised the value of DCog. The domain is characterised by specialised decision-making and technology to support such decision-making. The decisions to be made often have high impact, and usually a complex interaction involving both humans and technology can be found. As similar to the HCI domain, a DCog perspective can not only provide an alternative to how main concepts are portrayed within the domain but also be used as an analysis tool with which to understand the interaction between humans and technology.

For instance, it is argued that Medical Informatics traditionally has an individual-centred model of cognition (Hazlehurst et al., 2008). Likewise, it is argued that an internalised view of cognition can be found in medical decision-making in general (Patel et al., 2002). Consequently, it can be argued that the domain has the same heritage as the HCI domain.
Both Patel (2002) and Hazlehurst et al., (2008) theoretically argue for DCog as a possible approach to take the discipline further. In recent years, DCog has actually provided insights regarding co-ordination in emergency centres (Artman & Waern, 1999; Blandford & Furniss, 2006; Xiao, Lasome, Moss, Mackenzie, & Faraj, 2001) and operation theatres (Hazlehurst et al., 2007), patient safety (Nemeth et al., 2004), work practice (Cohen et al., 2006; C. Nemeth, O’Connor, Klock, & Cook, 2006), human-technology interaction (Alač & Hutchins, 2004; Cimino, 1998; Horsky, Kaufman, Oppenheim et al., 2003) and redesign of medical systems (Galliers et al., 2007; Rinkus et al., 2005).

Interestingly, Hazlehurst et al., (2007) note that DCog has been applied in slightly different ways, in terms of the perspective taken in the conduct of analysis. Their study focused on the activity being performed, the tasks being accomplished, and the coordination devices used when interacting in this structured environment (Hazlehurst et al., 2007). More specifically, the focus was on the action within the activity system. Resources within this system were treated as distributed and engaged, concurrently or serially, by multiple agents in the conduct of activity. This perspective should be seen in contrast to the study of a user interface of a computerised physician order entry system which took the perspective of the individual in its analysis, that is, the individual and the manipulation of the artefact is regarded as the boundary of the analysis. Furthermore, Hazlehurst et al., (2007) also report on a study which focused on investigating the artefacts used at different abstraction levels (organisational, individual). That is, DCog is, as currently constituted, open for interpretations.

5.4 Methodological Issues

Hutchins (1995a; 2001) makes an explicit distinction between DCog as a theory and (cognitive) ethnography being the method. In short, “[t]he method of cognitive ethnography combines traditional long-term participant observations with the micro-analysis of specific occurrence of events and practices. The cognitive aspect of the observed practice is revealed in the detailed micro-analysis. The two sides of the research, the micro analysis and the larger ethnography, are independent” (Alač & Hutchins, 2004, p. 4). Indeed, there is an inherent commitment to ethnographic studies in DCog due to the belief that the phenomena we are interested in cannot be disconnected from the cultural and social phenomenon (Hutchins, 1995). That is, we need to study the phenomenon in real settings. Using a lab would construct an alternative social situation which would affect the outcome of the study (Hutchins, 1995). Hence, most studies use a method which seeks to describe how human agents create and interact with external structures and artefacts (Perry, 2003).
The specific data collection methods (e.g., video recordings, direct observations, interviews) used for collecting empirical data can vary. Actually, it is argued that the analyst is free to use the method of data collection he or she believes is most useful for the domain they are interested in studying (Perry, 2003).

Considering the analysis of the collected data, there is no acceptable analytical method within DCog, that is, there is no single “correct way” to analyse the data (Cohen et al., 2006). The analysis can focus on many different aspects of DCog. For instance, it is argued that “[t]he key components of the analysis are two elements- the representations that information is held in and transformed across and the process through which these representations are coordinated with one another” (Perry, 2003, p. 183). According to Perry (2003), one needs to describe: “(1) the background to the activity - the goal of, and the resources available to, the functional system. They will need (2) identify the input and the output to the functional system, (3) the representations and the processes that are available, and (4) the transformational activities that take place in the problem solving when achieving the functional system’s goal” (p. 213-214).

Looking at various DCog analyses, this format is however not always followed to the same extent. Some analyses focus on the physical, organisational and social setting of work, e.g., Cohen et al., (2006), and less on transformation of representations, such as Cox et al., (2007). Others focus on the artefacts role as an extension of cognition or coordination devices (Fields et al., 1998; Hazlehurst et al., 2007). The unit of analysis can also vary, e.g., Hazlehurst et al., (2007) define the concepts as follows: “Unit of analyse has been on ... coordination devices in activity systems”... “activity system comprised of actors, and tools, together with rules and understandings that guide interactions in a structured environment or workplace” (p. 539). Interestingly, it should be noted that many researchers are actually attracted to DCog because they perceive the flexibility in use as an appealing feature.

5.4.1 Using Distributed Cognition as a Foundation for New Methods

Although DCog has been successful as an analytical tool (cf. Section 5.3), there is some criticism. For instance, it has been argued that it is necessary to structure DCog, in order for it to be successfully implemented in new domains (Moore & Rocklin, 1998). Furthermore, Perry (2003) argues that it has had limited success in the development of practical applications and recommendations for systems’ designers, mostly due to the narrative style of produced descriptions. It is argued that such qualitative and subjective data is not useful to system engineers. Similarly, Ferruzca et al., (2007) argue that there is a lack of a process for mapping ethnographic data to the theoretical concepts. Blandford and Furniss
(2006) also argue that there is a lack of a methodology for the process from analysis to design. Likewise, Rogers (1997) argue that DCog is not a methodology which can be easily applied to a design problem.

More recently, a set of attempts to structuring the DCog framework into a step-by-step description has emerged. In other words, they have tried to develop a method tailored to specific domains and goals. This can be seen as a response to the previously mentioned limitations. It is especially striking that all of the methods were developed and implemented in recent years, potentially indicating a new direction of DCog. In the following subsections, the different methods are outlined and their possible impact for the work of this thesis is elaborated upon. The methods presented have been chosen because they are named and presented as a “new method”.

**The Resource Model**
The resource model (Fields et al., 1996; Wright et al., 2000) is a method developed for modelling HCI. The focus of the method is to identify “‘what information is required to carry out a task and where should it be located, as an interface object or as something that is mentally represented to the user’. In other words, the user brings a set of resources to the interaction in the form of his or her knowledge and experiences. Similarly, ‘system resources’ such as dialogue boxes, buttons, and help facilities guide the interaction in specific ways. These can be categorized and quantified. The relative differences in the distribution of representations (internal and external) are central in determining the efficacy of a system designed to support a complex task. This model includes a characterization of abstract information structures (i.e., resource types) that can be used to analyze interaction. How these information structures are realized in interfaces will critically affect the quality of user interaction” (Horsky, Kaufman, & Patel, 2003, p. 295). The method aims at functioning as a tool for analysing existing computer systems (cf. Table 5.1). There are a number of different studies published which use the method, e.g., Smith, Duke, and Wright (1999) and Horsky, Kaufman, Oppenheim, et al., (2003).

Due to the method’s focus on plans and interaction between a single user and technology (not including user to user interactions), it fails to capture the complex behaviour and the interdependencies between different entities within the fusion process. That is, the method puts the user in the centre of the analysis in comparison to, for instance, the information flow of the system.

**MAIA**
MAIA (Ferruzca et al., 2007) stands for “a methodology to analyse the interaction between the agents of a activity system”. The method has been developed in the context of learning systems to analyse how the current system is
used, and thereby supports the design of such a system. From the description, it seems that the method can work on existing systems as well as prototypes. The method describes the activity system of a task, at an activity level, but not at a representational propagation level (cf. Table 5.1). In detail, the authors argue that analysing an activity system can be done in three phases: (1) identification of the structural components of the unit of analysis, (2) configuring the analysis of the interaction between agents, (3) developing the analysis. The main part of the method is the modelling framework which was developed to identify agents and their relationship. The agents were as follows: objective or purpose, unit of analysis, subject, artefacts, context, organisation, product, and task. A case study exemplified the method. The case study involved designers working on the design of a learning system for a distance course about mental health.

The focus of this thesis is to capture interactions within semi-automated fusion processes; consequently, this method is not applicable as it does not allow for such a focus. The method is currently used as a tool for designing future systems rather than understanding existing ones. Also, the method does not focus on information propagation and representational states.

**DiCoT**

The method “Distributed Cognition for Teamwork” (DiCoT) (Blandford & Furniss, 2006) has been developed to reason about group work and the design of artefacts to support such work. DiCoT is based on DCog and inspired by contextual design. It consists of three main parts: (1) a set of principles derived from DCog literature, (2) a set of diagrammatic representation to illustrate identified phenomena, and (3) tabular representations which can be used to summarise the analysed system. In detail, the principles refer to the physical layout, the information flow within the system and the artefacts used. By using the principles and the illustrations to structure the data it becomes possible to reason about re-design. See Table 5.1 for a summary of the method.

This method is limited because it does not provide any explicit support for how the different artefacts are used to support the overall process. By defining a set of individual principles, the authors allow the interaction and the interconnectivity between different parts of the system get lost. Hence, this method would only provide limited information regarding the interaction within semi-automated fusion processes and its support to decision-making.

**HCDID**

The abbreviation HCDID, stands for “Human centred Distributed Information Design”. The method has been developed in the context of the design of a distributed knowledge management system (Rinkus et al., 2005; Zhang, Patel, Johnson, Malin, & Smith, 2002). This method claims to capture complex,
independent, social, cultural, organisational and cognitive characteristics of the studied environment. It is put in the context of a system development process (here, a project design lifecycle including the phases: data collection and analysis; systems requirements; specifications; prototype). It includes different activities such as user analysis, functional analysis, task analysis, and representational analysis (the representational effect of information). It allows the researcher to use different data collection method depending on the phase of the methodology, for example, observations, document review, interviews, and so on. Typically, HCDID informs system requirements (e.g., functional requirements, goal-sub-goals relations, task structures and procedures, and information flow dynamics).

It can be highlighted that the method does not focus on representing information at a representational state level and the display of information propagation. It can be hypothesised that to capture the semi-automated fusion process one needs to focus on interaction between humans and technology and information propagation over time. Also, this method does not explicitly focus on capturing interactions and understanding the existing systems, rather this is a system development method ranging from data collection, system requirements to prototype generation.

**DCW**

Distributed Cognitive Walkthrough (DCW) (Eden, 2007; 2008) is a method extending cognitive walkthrough to incorporate a DCog perspective. (cf. Table 5.1). The method can be used to make an expert evaluation of an interface. The basic idea of the method is to “walk through” the interface and answer 4 DCog questions: (1) will the way that the information is presented provide all the knowledge required to carry out the task? (2) will the way information is represented show relevant previous progress towards the overall task? (3) will the way information is represented provide resources that relieve the user from having to figure out or calculate anything in his or her head while carrying out the task? (4) if the current task is accomplished, will the way that information is represented be changed in a way so that the result of the task is accessible by the current or other users at a later time or a different place? That is, the questions focus on the identification of what is externally represented, thus potentially helping the user to solve the task and determine what can be accessible to other after the interaction session. The overall aim of the method is to identify parts of the interface which need to be re-designed.

This method is not suitable to proceed with in this thesis, since it focuses on a limited system in the sense that it involves one single individual working with one single artefact (e.g., computer system). The underlying assumption when dealing with semi-automated fusion processes is that you have more than one
information source. In this thesis we are also interested in decision-making activities. Thus the method is not applicable.

**DIB**

Another method called “Determine Information Flow Breakdown” (DIB) (Galliers et al., 2007) is designed for identifying information flow breakdowns in the context of clinical systems. Thus, the method focuses on analysing current work settings. The method is divided into the following phases: (1) data gathering, (2) modelling the distributed cognitive system (this involves creating an activity template, textual descriptions, scenarios, and diagrams), and (3) checklist analysis (the data is evaluated regarding a set of questions). The aim of the method is to identify information breakdown (cf. Table 5.1).

The method is interesting as it has an underlying focus on information flow. However, the method is tailored towards identifying information at specific instances in the medical system (involving both digital and physical artefacts as well as humans). The method thus does not focus on propagation of information rather the focus is on, e.g., the duplication of information (i.e., different representational format). Also, the method does not include a focus on representational states.

**EAST**

“EAST” stands for the Event Analysis for Systematic Teamwork method (Salmon, Stanton, Jenkins, Walker, & Rafferty, 2010; Stanton et al., 2005; Walker et al., 2010). It is a descriptive method to be used in command and control settings. The method recognise the need for a multidisciplinary approach for capturing command and control and thereby integrates seven different methods (hierarchical task analysis, coordination demand analysis, communication usage diagram, social network analysis, propositional network, an enhanced form of operation sequence diagram) to enable a DCog perspective.

The advantage of this method is that it can capture technology mediation and communication (irrespective of whether it is human or non-human) through social network analysis. Also, it has a focus on representational states as a unit of analysis. However, the supporting function of the artefacts is somewhat overlooked. That is, this method would not capture the interrelationship between decision-making and the fusion process.

The characteristics of the above methods are presented and contrasted in Table 5.1.
Table 5.1. Summary of DCog methodologies

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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>Human computer interaction</td>
<td>Learning systems</td>
<td>CSCW</td>
<td>Knowledge management systems</td>
<td>Human computer interaction</td>
<td>Clinical system</td>
</tr>
<tr>
<td>Purpose</td>
<td>Model interaction</td>
<td>Create new design</td>
<td>Re-design</td>
<td>Re-design</td>
<td>Re-design</td>
<td>Identify information breakdowns</td>
</tr>
<tr>
<td>Utilisation</td>
<td>Analysis</td>
<td>Analysis</td>
<td>Analysis, design</td>
<td>Analysis</td>
<td>Analysis, design</td>
<td>Analysis</td>
</tr>
<tr>
<td>Requirement</td>
<td>Undefined</td>
<td>Concept/idea</td>
<td>Existing system and users</td>
<td>Existing system and users</td>
<td>Prototype</td>
<td>Existing system and users</td>
</tr>
<tr>
<td>Outcome</td>
<td>Model</td>
<td>Recommendations</td>
<td>Recommendations</td>
<td>Principles, guidelines</td>
<td>Recommendations</td>
<td>Recommendations</td>
</tr>
<tr>
<td>Data collection method</td>
<td>Observations, expert evaluation</td>
<td>Expert evaluation (no users), questionnaire</td>
<td>Observation, contextual inquiry, interviews</td>
<td>Observation (video recorded), document reviews, interviews,</td>
<td>Expert evaluation (no users)</td>
<td>Observations, interviews</td>
</tr>
<tr>
<td>Documentation produced</td>
<td>Text descriptions</td>
<td>Text description s, models</td>
<td>Text descriptions, illustrations</td>
<td>Text descriptions</td>
<td>Text description s</td>
<td>Text descriptions, activity template, scenarios, diagrams</td>
</tr>
<tr>
<td>Focus</td>
<td>Cognitive support</td>
<td>Cognitive support</td>
<td>Information flow</td>
<td>Cognitive support, information exchange</td>
<td>Cognitive support</td>
<td>Information flow</td>
</tr>
</tbody>
</table>

Additional Methods and Tools

Another approach is the one presented by Cox et al., (2007) who developed an observation tool (which is unnamed) to study air traffic control and flight deck Collaboration. The overall aim of study was to examine the use of artefacts to facilitate communication and coordination in teams, and in that way identify the possible effect of changes to the system. The study started with a familiarisation phase which included data collection methods such as literature reviews, interviews, and direct observations. An observational tool was developed to specifically aid the direct observations. The tool (a sheet of paper with specific columns) enabled a more structured approach to field data collection by guiding the researcher to specific elements of the system. It was believed that this would increase the ability to compare different features of the system. The tool focused
mainly on the propagation of information within the system, that is, the sequences of events taking place (what activity followed another one) as well as duration and the frequencies of activities. The tool included categories, such as flight phase, time, callsign, communication (initiator, receiver, audience, mode, content), and the trajectory of information. The final trajectories and representational states were visualised.

In addition, Paternó and Santoro (2006) developed a method (which is unnamed) for use by system designers to manage the design space when developing safety-critical applications. The focus of the method is to consider the impact of context on hazards in task performance and thereby identify possible improvements to the design. The goal of the method is to improve usability while preserving safety. The method differs from the previous ones by extending a deviation analysis (i.e., “systematic analysis of potential effects in case of deviations for the task plan” Paternó & Santoro, 2006, p. 1546) with a DCog perspective. This combination gives a wider perspective to the deviation analysis to include the context of use and the impact of different representations. The goal of the analysis is to provide an understanding of whether the information representations yield sufficient support. Thus far the following attributes have been identified: externalisation, accessibility, access modality, mobility, sharing, persistence, flexibility of modifying the representation, comparability, combinability, ease of production.

**Visualisations and Modelling Approaches within DCog**

Traditionally, DCog does not provide a way to illustrate concepts and structures. Despite this, many researchers feel the need to illustrate phenomena emerging from the analysis, that is, to illustrate concepts emerging from the text based description. Consequently, there are many different ways to illustrate DCog concepts. Despite individual differences, there are similarities in what one chooses to illustrate. For instance, most often, the physical layout is captured (Artman & Waern, 1999; Blandford & Furniss, 2006; Cohen et al., 2006; Hazlehurst et al., 2007) as well as individual artefacts (Hutchins, 1995b). In addition, the general structure of information flow is illustrated (Artman & Waern, 1999; Hazlehurst et al., 2008; Nemeth et al., 2006; Rinkus et al., 2005). It is less common to provide a conceptual structure of the concept used such as Ferruzca et al., (2007) and Perry (1998) or provide an information flow on a representational level as similar to Cox et al., (2007). When making the illustrations, pictures/drawings (Baber et al., 2009; Cohen et al., 2006; Horsky, Kaufman, Oppenheim et al., 2006; Paternó & Santoro, 2006) provide a way to illustrate phenomena emerging from the analysis, that is, to illustrate concepts emerging from the text based description.

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18 Note the similarity between this method and DIB (Galliers et al., 2007) which also aims at capturing breakdowns, deviations in the health care domain.
2003; Wright et al., 2000) or graphical representations (Cohen et al., 2006; Cox et al., 2007) are typically used, while simplistic symbols such as Halverson (2002) are less popular. That is, it is reasonable uncommon for researchers to develop their own notations, an exception include McMaster et al., (2006). It is also not that common to include computational approaches when performing the analysis similarly to Walker et al., (2010) who use social network analysis, and can thereby calculate the centrality of individual agents.

It is thus recognised that there is no common way to model and visualise findings in DCog and, hence, the development of a tailor made visualisation notation is required.

5.5 A Distributed Cognition Perspective on IF

Just as DCog has enriched disciplines, such as HCI and Medical Informatics, it can enrich IF. One can argue that IF still relies on a traditional HCI/cognitive perspective similar to, for example, Medical Informatics (cf. Section 5.4.3). To our knowledge, in today’s research in IF, the power of DCog is not elaborated, although, the phenomena are implicitly touched upon, as Blasch and Plano (2002) indicate: “A user fuses data and information over time and places and acts through their world mental model- whether it be in the head or with graphical displays, tools, and techniques” (p. 195). Despite a lack of awareness, DCog can have a major impact for IF research both as an explanation tool for concepts and as a way to analyse interaction between decision makers and IF technology.

Theoretical Implications

As introduced in Chapter 1, DCog can have a major impact on how the fusion process is portrayed. Traditionally, the process is considered to take place in the computer. It can be argued that the perspective needs to be extended from thinking of fusion as a processes solely taking place in computers, to thinking of IF processes as those including humans and their surroundings. In other words, we need to widen the perspective of the fusion process as a computational approach (cf. Chapter 3). Traditionally, a fusion system typically refers to the type of computer system characterised by the JDL model (levels 0-3), the process of transforming low-level sensory data to higher-level more abstract information. With a DCog perspective, an IF process, on the other hand, would also include the context of the user(s), the material surroundings, the organisation they are part of, and so on. This distinction can be enhanced by referring to fusion processes as either “automated fusion processes” or “semi-automated fusion processes”. More specifically, the fusion emerges in the interaction between the components of the system which includes both the technology and the decision makers. Thus, DCog can provide a suitable approach for the study of humans as
an actual integral (active) part of the IF process. DCog concerns creating something more which cannot be achieved through the individual parts; it considers individuals with their different roles and tasks, as well as the overlap between them. As a result, a new shared understanding and meaning emerge. Indeed, “… effective and efficient interactions between the fusion system and the user, the sum (as defined in the metrics) should be greater than the separate parts” (Blasch, 2003, p. 466). Hence, the user is no longer only regarded as a mere observer of an IF system, instead, humans are included in the IF process. In other words, DCog can provide IF researchers with an alternative framework for understanding the emergent properties of the fusion process, and how it is distributed between humans and technology. However, DCog should still be recognised as a valid tool in IF.

**Practical Implications**

In addition to the theoretical impacts, a DCog perspective can have major practical implications when analysing the interaction between the decision maker and IF technology. For instance, using a DCog perspective provides the terminology needed to identify the interactions between the different decision makers and the interactions connected to the IF system. Hence, the actual IF process can be captured. However, looking at the current state of DCog as an analytical tool, there is a need to tailor the DCog framework for capturing the characteristics of fusion processes. As previously argued, there is a need to formalise the approach in order to successfully introduce it to new domains. Even though many great ideas are currently being developed, none of the attempts would capture all aspects of the fusion process. Galliers et al., (2007) present a simple structure which can be used as a starting point for a method tailored specifically for the characteristics of the IF community. As their method lacks a modelling approach, inspiration can be taken from Ackerman and Halverson (2004) and Cox et al., (2007), who show successful attempts in capturing the transformation of representational states. That is, the method presented in the thesis (CASADEMA) is thus a synthesis taking inspiration from previous methods based on a DCog perspective.

**5.6 Reflective Summary**

Despite DCog’s ability to successfully inform many different domains, such as HCI and Medical Informatics, it has only been successful in assisting in the development of practical applications or recommendations to system designers to a limited extent. It is argued that there is, for instance, no acceptable analytical method within DC, that is, there is no single “correct way” to use it (Cohen et al., 2006). There is much variability in the field of DCog (Walenstein, 2002) and as
Heylighten, Heath, van Overvalle (2004) argue: “in spite of its promises DCog has yet offered little more than a heterogeneous collection of ideas, observation techniques, preliminary simulations and ethnographic case studies. It lacks a coherent theoretical framework that would integrate the various concepts and observations, and provide a solid foundation that would allow researchers to investigate varieties of cognitive systems”. However, proponents of DCog argue that it can explain all cognitive phenomenon (Hutchins, 2001). Whether this is true, is still an open research question. Properties like motivation, for instance, are still unexplained in a DCog framework. Indeed, in DCog all agents are supposed to perform work in the same way, whatever their personal concerns (Perry, 1998). It should therefore be noted that DCog, as a theoretical framework for the explanation of cognition, is still debated (Perry, 2003).

Considering the methodological abilities of DCog, there is a recognised need for a more precise and comprehensive, formulation in order for DCog to be more easily applicable in other research areas (Moore & Rocklin, 1998). Consequently, some researchers have investigated whether or not it is possible to provide a taxonomy or similar consensus of DCog (Sutton, 2006). If DCog is to be introduced to a specific domain, such as IF, we therefore believe it is necessary to structure DCog into a method.
CHAPTER 6
Complementary Empirical Studies

This chapter outlines empirical studies performed early in the PhD process, aimed at providing knowledge of the relationship between decision makers and IF technology, beyond the theoretical investigation presented in Chapter 3. The studies are presented in chronological order. In particular, the presented studies depict situations where the decision maker largely needs to rely on the output of the fusion process (compared to being an active part of it). These studies provide additional insights regarding the IF domain and the relationship between human decision making and fusion.

6.1 Study A: Field Study Capturing Current Decision Making

Study A was performed in a marine surveillance control room responsible for the security of an area outside the Swedish coastline. The main task of operators, located in the surveillance control room, was to identify vessels and continuously analyse the situation, staying aware of the current state at sea, and thus, be able to identify possible suspicious behaviour (e.g., foreign vessel entering Swedish water without permission). To assist in their task, they had an overview display which showed the output of the identification and tracking process of vessels. They also had access to a number of additional technologies (e.g., radio, surveillance boats, airplanes, optic camera etc.) which, when needed, can provide further information regarding the identity of a vessel (e.g., they can use the optic camera to zoom in on the name of the vessel to determine its identity).

The focus of the study was to capture what operators base their decisions on when determining suspicious behaviour (e.g., a boat in need of further investigations). In other words, the focus was to capture operators’ Situation Awareness (Endsley, 1995). In particular, the study was concerned with the following question: how do operators in a maritime surveillance control room...
classify anomalies when interacting with a situation picture (graphical overview display), that is, when and what triggers users to make a decision or take action?

The goal of the study was to collect knowledge which to inform a developed prototype (i.e., a prototype involving JDL Level 2 (situation assessment) functionality). The prototype to be informed was in the form of a rule based expert system aimed at alerting operators, working within maritime surveillance, of interesting situations. These alarms are created by implementing rules which combine different attributes (e.g., location, speed, history, owners, etc.) in order to draw conclusions.

The study consisted of a set of observations involving 7 operators with an average of 3 years experience. Participatory observations (Waddington, 2004) were chosen as the method of extracting knowledge regarding the interpretation of the data presented in the overview picture. The method of participatory observation allows the user to answer questions and to instruct the observer in their work. Actually observing how a system is used in practice can differ considerably from how the system is expected to be used, even by the end-users and developers. No additional guidance from a theoretical framework was used (for full details regarding the study see Nilsson, Laere, Ziemke, & Edlund, (2008)).

6.1.1 Procedure

The observations were conducted on 4 occasions (including a pilot test) distributed evenly around the clock to allow for different conditions, for a total of 16 hours. Approximately 70 vessels were identified and tracked during the observations by the team of users. When necessary during the observations, users were asked to explain the reason for taking a specific action. Participatory observations allow users to explain their actions at the same time they are being performed (i.e., the focus is not only on what they know, but on how they actually use that knowledge). Field notes (pen and paper) were used to capture work procedures and events which can later be formalised into rules. A summary of the resulting rules were verified by two of the operators for validity.

6.1.2 Analysis and Results

The participatory observations resulted in a collection of field notes on how the team of operators interacted in the control room, in order to be aware of events at sea. The results revealed a number of interesting factors concerning situation awareness.
At the beginning of a shift, the operators need to quickly gain an understanding of the current situation. Currently this is supported through, for example, a formal debriefing by the previous work team, a specific daily report, and informal chats with colleagues. It should be noted that more information than that provided by the overview display is needed to build an awareness of the current situation, that is, the cues provided by the overview display are not, in themselves, sufficient to create an accurate understanding of current events (situation) occur. That the overview display does not provide enough information is exemplified by the fact that information is assessed differently depending on the time of day or year. One of the operators explained that in July one typically sees a large number of boats/ships travelling from Germany towards Sweden, cluttering the display. An automatic anomaly detector can trigger an alarm, but the reason for the large amount of activity is that July is the start of the main holiday season in Germany. The limitations of the overview display are also reflected in the debriefing where not only a snapshot of the overview display is provided but also actual photos of the vessels in the area. Operators reported that photos not only made their work more enjoyable, but they felt they got a better impression of what kind of vessels were in the area.

Furthermore, it was observed that each team has to start its work from scratch. That is, knowledge of the current situation is just summarised in the form of a PowerPoint presentation which includes the position and identity of vessels, but not the achieved situation assessment. This may thus lead to a lack of episodic reasoning, since such reasoning is not transferred between the work teams.

The work is currently divided between the different operators, to be able to maintain situation awareness, that is, the two operators responsible for identifying vessels alert the ones responsible for the overall situation, if they see any suspicious behaviour. The operators have different ways of assessing the overview display. A summary of factors affecting this assessment of suspicious detection is as follows:

- **Experience.** Depending on experience, the overview display can trigger different information. In particular, a difference was noted between the operators with less than a year’s experience and those with longer experience. Those with more experience, are more likely to know what temporal and spatial patterns to look for.

- **Context.** The context of an event can classify it as suspicious behaviour. It was emphasised that flexibility is required when interpreting the overview display, a pattern that is of interest one day, may not be interesting the another day.
- **Incoming reports.** Intelligence reports or other information from, for example, the coast guard or Command superiors can provide information about interesting objects. The operators can be told to look for a specific pattern in the overview display.
- **Permits.** There are official documents describing what vessels have the right to be in Swedish waters.

It was further noted that differences exist between operators regarding what they identify as suspicious in the overview display. At one point, two of the operators were asked to make an individual assessment of the situation from the information provided by the overview display. The operators’ assessments overlapped; however, there were individual differences between them, in terms of what conclusion they drew from the overview display. Moreover, it was noted that the operators had different working procedures, hence, there is a demand for the personalisation of rules. Also, there was a difference in the operators’ extent of awareness regarding their knowledge and how well they could articulate it. In other words, some could express a specific reason for taking an action or making a decision, while others were unable to express why they took a specific action (they just reacted to the information on the display). It was also noted in the observations that the users had difficulties maintaining situation awareness of the overview display, since it presents a quite constant state. Often the two operators responsible for the overall situational picture were occupied with side tasks, and only, occasionally, looked at the overview display.

**Examples of Rules**
The participatory observations resulted in a collection of field notes regarding the causes of actions, which could then be identified and formulated as different rules. It was noted when and why users decided to act upon the information provided by the overview display. Some of the identified activities were routinely performed, that is, one can have standard rules implemented into the system. Others were instances of special occasions which would require the possibility of adopting and adding new rules. One example situation which the operators would like to be notified of is when a new vessel, entering the overview display, is government owned. Hence, one identified rule to be implemented in the developed prototype is: if a vessel is government owned then the operator needs to be notified. A total of 11 rules were identified. Looking at the identified rules, they consist of different components, mostly they are:

- relations (binary, unary)
- combination of future state and attributes
- combination of physical (border) and abstract
Chapter 6 Complementary empirical studies

- (land) attributes
- describing situations evolving over time

6.1.3 Reflections

Several interesting aspects were highlighted in this study, regarding the relationship between decision makers and IF technology (cf. Table 6.1). For instance, as an operator, additional information is needed to gain an understanding of the current situation beyond what is presented on the overview display. What is illustrated in this study is that the identified rules emerge from organisational factors (e.g. operators have a task to identify government owned vessels and are provided with lists of interesting objects and different permits), team work (operators collectively have knowledge which is used to identify suspicious behaviour) as well as their individual experience (some of the rules are created from operators’ previous experience). That is, even though the system supports situation awareness, the users are dependent on other factors which an overview display cannot transmit in order to achieve a certain level of situation awareness. Situation Awareness is thus beyond what is typically denoted “situation assessment” (relations between objects) in the JDL model level 2.

Table 6.1 Summary of Study A. A field study in combination with participant observations

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Methodology attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>Surveillance</td>
</tr>
<tr>
<td>Focus</td>
<td>Informing prototype development, work practice of finding</td>
</tr>
<tr>
<td></td>
<td>anomalies</td>
</tr>
<tr>
<td>Level of analysis</td>
<td>Macro</td>
</tr>
<tr>
<td>Study object</td>
<td>Existing decision-making situation</td>
</tr>
<tr>
<td>Issues investigated</td>
<td>Decision-making needs, decision support usage</td>
</tr>
<tr>
<td>Documentations</td>
<td>Text descriptions</td>
</tr>
<tr>
<td>Result (output)</td>
<td>Information regarding decision-making rules, specific data</td>
</tr>
<tr>
<td></td>
<td>with details</td>
</tr>
<tr>
<td>Positive aspects</td>
<td>Capture real work,</td>
</tr>
<tr>
<td>Level of formality</td>
<td>Flexible observations</td>
</tr>
<tr>
<td>Requirements</td>
<td>Pen and paper</td>
</tr>
<tr>
<td>Effort</td>
<td>Difficult to capture behaviour with pen and paper, no formal</td>
</tr>
<tr>
<td></td>
<td>data, takes long time to perform the study</td>
</tr>
</tbody>
</table>

Furthermore, there is a problem of identifying situations that evolve over time, due to the changing of shifts. There are also problems of maintaining awareness and paying attention to an overview display which does not often significantly change state. A rule based prototype which takes into account the operators’ knowledge could ease these problems, by being able to operate over
time and shifts, alerting operators and directing their attention towards interesting situations, such as those the previous identified rules exemplify.

Moreover, the field study in combination with participant observations worked well with regard to capturing present decision-making activities as well as informing the developed prototype. However, the study was limited in terms of only being able to, for example, identify rules used on that particular day. That is, there was no explicit focus on capturing retrospective decision-making. A summary of the characteristics of Study A is presented in Table 6.4.

### 6.2 Study B: Simulation and Structured Interview based Approach

Study B was an explorative evaluation of a military application, *Impactorium* (see Svenson, Berg, Hörling, Malm, & Mårtenson, 2007 for details), which utilised IF to combine incoming intelligence reports in order to make predictions of future events, and thereby support human decision-making. In comparison to study A, this application covers JDL Level 3 (impact assessment) functionality. The study focused on exploring the possible utilisation of the prototype by the intended decision makers (i.e., military commanders). The tested tool aims to enhance situation awareness. In particular, the prototype uses fusion techniques to combine incoming intelligence reports in order to make predictions of future events, and thereby support human decision-making.

To explore the usage of the prototype, a scenario representing a possible situation in which the tool can be used was developed, creating a realistic simulated decision environment. This situation can then be used as a basis for interviews targeting decision-making aspects (cf. Klein et al., 1989). For full details regarding the study, the reader is directed to Nilsson, Laere, Ziemke, Berggren et al., 2008.

#### 6.2.1 Evaluated Tool

Impactorium is a decision support application based on IF to be used as a tool for today’s commanders when handling various incoming intelligence reports. More specifically, the tool consists of an impact matrix which informs users of possible future events. The impact matrix presents the user with the probability of an event and provides the background information which leads to a conclusion. The matrix also organises the events according to their likelihood of occurring and according to what impact they would have if they did occur.

Each future event carries information about what indicators and observations have prompted the event, that is, a description as to why the system
has reached a particular conclusion is provided. In addition to the matrix, the user has, through the tool, access to the incoming reports and a map displaying their origin (location). In other words, users’ decision-making processes can, potentially improve by “keeping track of which available information could be linked to potential future events” (Svenson, et al, 2007, p. 7).

6.2.2 Procedure

The study was conducted during two sessions at the Swedish Life Guard training unit and its international training department. A total of 4 Swedish commanders participated in the evaluation. Two of them have a background in national military operations and were training for participation in international peace-keeping operations in Kosovo during autumn 2007 (participating in test occasion 1). The other two had recently participated in international operations in Kosovo during autumn 2007 (they participated in test occasion 2 the day after their return to Sweden). A scenario similar to the ones which the European battle group needs to deal with on a daily basis in Kosovo was implemented in the tool to simulate parts of the decision-making environment.

The first session was structured as follows: the test started with a training session for the participants to familiarise themselves with the application. The participants were given a short introduction and asked to individually explore the system. After the training session, the users were given the task of the cooperative planning for the transportation of VIP persons between the airport and the military base. At the same time, they were asked to keep track of what was happening in the tool. This side task was to simulate a more natural situation. The participants were observed during the completion of the task, after which they were interviewed together. The interview questions followed an interview guide of open-ended questions. Although, the guide was not strictly followed, it allowed for improvised questions depending on the participants’ answers. The interview guide was divided into three main categories, that is, decision-making (Hutchins et al., 1996; Klein et al., 1989), trust (Bisantz et al., 1999), and HCI (Hall et al., 2001) issues. The study took approximately 1.5 hours to complete, and the interviews were transcribed.

As the participants did not interact with the tool at a satisfactory level in the first session, a change in set-up (procedure) was carried out. On this test occasion, no side task was given.

The second session was structured as follows: the participants were given a presentation of the tool and had the possibility of testing it for approximately 10 minutes. This was followed by a structured interview which lasted for approximately 45 minutes. The participants were interviewed together in order to allow them the possibility of triggering each other. The interview was recorded
and during it the participants had access to the tool. In addition, the interview was characterised by semi-structured interview questions which aimed to capture the usefulness of the tool. The questions followed an interview guide but allowed for improvised follow-up questions. Moreover, the same interview guide was used as in the previous study, and the interviews were transcribed.

6.2.3 Results
The result is based on the transcriptions of the interviews conducted during the two test occasions. These transcriptions have been individually analysed by two researchers (the author of this thesis being one of them), see Nilsson, Laere, Ziemke, Berggren et al., (2008) for full details.

Better Situation Assessment
Today, there are only limited possibilities of getting an overview of the current (as well as future) situation. All the interviewed decision makers appreciated the idea of receiving information in terms of situation understanding (map with reports of current events) and impact assessment (probabilities of future events) because it would enable them proactive decision-making. In their own words, they characterise their decision-making process as guided by the “here and now” (i.e., reactive decision-making), even though they want to be more efficient and focus on proactive actions. In general, there is a strong belief that the system prototyped here can be very helpful in supporting decision-making in operations common for the Nordic Battle group, one of the European Union Battle groups. The prototyped application is believed to be able to process more information and archive it in a more searchable way; hence, making it more accessible to the decision makers. In addition, the interviewees especially appreciated that reports were linked to a specific location on the map. A searchable archive of events and traceability of reports are considered as the most valuable aspects of the system.

“Quick and Dirty” Impact Assessment
The impact matrix received mixed reviews from the interviewed decision makers. On the one hand, the decision makers believe in the general idea, for example, “the system can give you a first fast interpretation of the current situation by the probability measures of events, the next one can check whether one agrees with the systems by checking the underlying reports”. On the other hand, the decision makers consider the information on the maps as much more valuable compared to the information provided by the impact matrix since “30% of the screen is used for useless information. It is better to have a large map and to let the probabilities only pop-up in case of a major change. The probabilities will most likely be stable and not change every 2 minutes”. Furthermore, the calculation
procedure was questioned, for instance, is there sufficient historical data to discern between accidental relations and causal relations? What is the logic or belief system behind these calculations? What if it was just a random event, how can that be accounted for?

**Supporting Situation Awareness**
The decision makers explained that it is important for a commander to have situation awareness of a specific geographical area (i.e., local situation awareness) as well as an understanding of what the other commanders are dealing with (i.e., global situation awareness). It was suggested that the situation map should provide information regarding a specific area, while the impact matrix can provide information regarding a larger area which includes, for instance, the overall mission including other commanders’ (who may be from other countries) activities.

**End Users are Intelligence Officers rather than Commanders**
Although the application has been envisioned as providing real-time support to decision makers working in the field, 3 of 4 interviewees stated that the application is better suited for the work of intelligence officers, as a tool with which to pre-process information for decision makers such as commanders. For a commander in the field, the application is too disorderly and contains too much invalidated or irrelevant reports. Therefore, intelligence officers are considered as the natural users of the developed tool “they [intelligence officers] need to present the conclusions for me so I can make better decisions”, or elsewhere, “only an experienced decision maker could have direct use of this system, for inexperienced ones it distracts too much from their main task, leading other people”. Also, “it is not our job to filter information and judge intelligence reports”. However, it should be noted that the tool was judged to be useful to the interviewees (i.e., commanders) in debriefing and training (non real-time situations).

**Long Term rather than Short Term Decision Frames**
In line with the observation that intelligence officers rather than decision makers are the end users of the system, the interviewees argued for a long term decision-making horizon (a week, a month) rather than immediate decisions based on real time information. For example: “under time pressure there is no time to analyse multiple inquiry reports of intelligence officers”, and “when one has chosen one’s strategy, there is no time to consider new information; one does not change an order lightly”. In addition, others regard trusting to much in the system as a potential danger “time is needed to validate incoming reports as well as control the relations the system is drawing, therefore it should not be used for immediate...
decisions, but on the contrary, the system can outperform humans in the long term, when it can signal relations with incidents a long time ago”.

**Decision Tradeoffs**
Two of the interviewed decision makers raised concerns regarding the probability distribution provided by the tool. When should the decision maker make the call, that is, what does having an 80% risk of kidnapping really mean? Does this indicate that the decision makers using the tool already should have made a decision (e.g., making phone calls alerting the relevant authorities)? As one of the decision makers puts it; “80% risk for an event, to me that indicates that I should have been on the phone making phone calls a long time ago, 80% chance for an event is not something you would like to have to deal with”. In their current work environment, a specific time or event is typically used as a turning point for making a specific decision (i.e., the situation can be allowed to escalate until a certain event occurs, at which point a decision is required). The decision makers’ raised concerns regarding how they should know the “exact number” functioning as a turning point for decision; i.e., there are interesting tradeoffs to be made.

**Recalling Headlines rather than Content**
The interviewees in study 1 were specifically asked to recall the situation as it was presented by the tool. When answering that particular question, they only recalled the headlines of the incoming intelligence reports, not their actual content. In addition, they mentioned all incoming reports, not just those of interest to their particular decision situation.

**Role based Customisations**
Depending on role, personal preferences, or the assignment one is currently performing, the decision makers argued that one can have very different needs. Therefore, they want to have more possibilities of filtering and selecting information in different ways, such as time frame (e.g., week, month), geographical area (e.g., a specific area of town), type of events (e.g., accidents, discoveries of weapons), and so on. This would provide flexibility in the tool to be adapted to different decision situations.

**Achieving Trust**
The decision makers reported that whether or not one relies on the application depends on whether one trusts the reasoning behind it (probabilities and relations between events), and whether it has performed well previously. Here, the traceability of the reasoning was considered very important. For instance, during the first study, it was noticed that the decision makers, when a rise in probabilities occurred, inspected the information regarding the reasoning behind
the probabilities. They also located the relevant intelligence reports in order to make their own judgement about whether or not the tool had given a sound interpretation, that is, indicating the importance of traceability of predictions. Also, the decision makers reported that there was a potential to trust the system too much, that is, you as a decision maker needs to trust the system either way, because there is no time to control the output of the system.

**Maintaining Control**

Some of the decision makers reflected upon the intelligence reports used by the system. If you as an informer see something and decide to make a report of the event, you do not have control of how the system will portray the report. That is, depending on the keywords you use in the intelligence report to describe, for example, a protest rally, it can be associated to different events in the tool, over which you have no control. One decision maker gave the example of a demonstration. A friendly protest rally can be misinterpreted as a critical event in combination with other events. The question raised was what if the protest rally was just a random event, how can that be accounted for? Furthermore, it should be ensured at some point that false information can be deleted and “that the system is foolproof: a poorly formulated report should not create a massive alarm of many resources”.

**Importance of Experience from Field Work**

Even though all the interviewees were positive towards the tool, there was one interesting issue which separates the two test occasions (study 1 & 2). The first study involved commanders prior to deployment in an international mission. Those decision makers focused considerably on the possibilities of the tool provided. The commanders in the second study who had just returned from an international mission were very focused on how the tool would actually work in the field in Kosovo. For instance, in the second study, specific concerns were made regarding how to act upon the provided predictions (i.e., how high does the probability need to be for me to take action). These issues were not raised by the decision makers in the first study.

**Selection of Suggested Improvements**

The interviewed decision makers suggested a number of different improvement aspects. Firstly, upon recognising the potential of the tool regarding incoming information, they wondered to what extent reports and other information sources in different formats could be automatically incorporated and translated into probabilities. This can be everything from paper written reports, faxes, and other computer applications, to weather predictions, newspaper stories, and UAV pictures. Historical data (written reports) can be extremely important in order to
build up a knowledge base for a certain area. Currently, much communication relies on spoken radio conversations, which are problematic with regard to automatically converting into a format that can be used for automated processing in a technical system. Several interviewees point to the importance of using a standardised report model to achieve some level of standardisation which can be problematic for (highly valued) reports from civil organisations. In addition, the interviewees questioned whether the knowledge base that contains relations between current reports and future events is context dependent. Can the Kosovo dataset be used in Afghanistan? Can the French database of Kosovo be used by the Swedes that succeed them? Finally, one can consider to what extent so called “soft information” from “informal contacts” can be used in this system. Such information can be taken into account, but normally it cannot be shared officially.

Secondly, the decision makers requested more filtering options for the incoming intelligence reports. For instance, one should be able to access reports within different time frames (e.g., using a timeline which can show all events of the last hour), different geographical areas (e.g., show events connected to a specific square), and on different topics (e.g., show all traffic accidents). The possibility for personalisation was also raised.

Thirdly, interviewees especially appreciated that reports were linked to a specific location on the map, but would like this aspect integrated with the possibility of showing the current location of different troops. In addition, it was suggested that the situation map would include information relevant to a specific area, while the impact matrix could provide information about a larger geographical area (thus, supporting local and global situation awareness).

Fourthly, it was noted that the information in the matrix seemed constant (i.e., does not change rapidly), therefore, they argued for the use of a pop-up box/menu that more clearly indicates changes in the status of a predicted event.

Fifthly, the decision makers were confused by the timeline of the system. For instance, for the intelligence reports which were listed, did the time indicate when the report was added to the system or when the actual event, which generated the report, took place? Also, the timeline of the intelligence reports included in the tool is not clearly indicated. One of the decision makers provided a scenario, “if I report one thing in 2003 and then 2009, will it be saved?” It was suggested that this would be more clearly indicated in future designs.
6.2.4 Reflections

There are a number of different aspects emerging from the result of the study. Firstly, one can draw conclusions regarding the interrelationship between fusion of information and human decision making. For instance, participants only remembered the headlines when asked to recall the current situation. The headlines of the intelligence reports are displayed on the list of incoming reports as well as on the map. The user is thus provided with two representations of the same information, hence, prompting the recall of the items. It may also be the case that they had not paid attention to the content of the reports, or that the titles summarised what was important to them as decision makers. In addition, when asked to describe the current situation provided by the tool, no selection or filtering of information relevant to their decision was made. Hence, the interface of the decision support tool had an effect on decision-making activities.

Secondly, there are conclusions drawn from how decision making is supported (i.e., supporting situation assessment versus impact assessment). In the study, it was identified that the tool can be used in two different ways: (1) to analyse incoming reports (filtering, organising, predicting future events, etc.) and (2) as a tool to provide situation assessment over a specific geographical area. There is an interesting trade-off between the usefulness of the situation map versus the probability distribution of future events. The results indicate that the impact matrix (i.e., probability distribution) was actually judged to be one of the least interesting features of the prototype, revealing that the situation map was more appreciated than the actual predictions provided by the tool. This demonstrates the importance of situation assessment rather than impact assessment for decision-making. The reason for this can be due to a number of different factors. For instance, compared to the decision-making situation the interviewees currently experience, the considerable difference that having access to the intelligence report and situation map would make for them is an exciting prospect. This is in line with their current work preference which sets the frame for their decision-making process. Thus a new tool which promotes impact assessment may have difficulties introducing another way of performing activities, since their current work is characterised by reactive decision-making (which is supported by situation assessment) rather than proactive actions (which is supported by impact assessment).

Also, the difference in appreciation between situation assessment and impact assessment might be due to the set-up of the studies. The interviewed decision makers were commanders working in the field and an intelligence officer with a more long-term time horizon might thus find the impact assessment more valuable. Moreover, it is possible that an insufficient explanation was given about how the probabilities were calculated. As a consequence, the result might be due
to trust issues, which need to be resolved. The interviewed decision makers judged the prototype’s calculation of the probabilities as difficult to interpret. The situation map was not pre-processed and they had to make their own interpretation. They therefore had a tendency to trust the situation map more than the provided probabilities.

The qualitative method (interviews) employed in this study explored the potential of the developed tool. As a result, a combination of observed behaviour with a citation from the interviews was noted. The study illustrates the applicability of explorative methods, such as interviews, in the early design phases of IF decision support, when general information regarding a concept is needed. The interviews raised interesting issues regarding control, trust, time frames, expert knowledge, and decision tradeoffs, which can be evaluated in more focused and controlled usability testing sessions. Also, the difficulties of using simulations to evaluate a decision support tool were exemplified in the change of procedures between the two user studies. It is important to realise that what was evaluated is how the decision makers think they would use the tool, not how it was actually used. A simulated decision situation cannot evaluate, for instance, trust, because it is complex and develops over time. Also, the tool shows how difficult it might be developing new tools which modify the current decision-making process. The fit between current decision-making activities and the new tool has an impact on how well the new tool will be accepted, hence, it affects the evaluation of the tool. Moreover, the study highlights the trade-off between evaluating the usability of the interface compared to the usefulness of the tool. What should be evaluated first? Should they be evaluated separately? This study does not provide an answer to those questions, only identifies the interrelationship between them. Table 10.3 provides a summary of the characteristics of the approach used.

**Table 6.2 Summary of study B. Interviews in the context of a simulated human decision-making environment**

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Methodology attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>Defence application</td>
</tr>
<tr>
<td>Focus</td>
<td>Evaluation of prototype, retrospective decision-making</td>
</tr>
<tr>
<td>Level of analysis</td>
<td>Micro</td>
</tr>
<tr>
<td>Study object</td>
<td>Prototype, simulated environment</td>
</tr>
<tr>
<td>Issues investigated</td>
<td>Decision-making needs, interface functionality</td>
</tr>
<tr>
<td>Documentations</td>
<td>Text descriptions, list of example decision situations</td>
</tr>
<tr>
<td>Result (output)</td>
<td>General knowledge, recommendations, high level of details</td>
</tr>
<tr>
<td>Positive aspects</td>
<td>no need for full scale systems</td>
</tr>
<tr>
<td>Level of formality</td>
<td>Formal and structured</td>
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<tr>
<td>Requirements</td>
<td>Interview skills, tape recorder, pen, paper</td>
</tr>
<tr>
<td>Effort</td>
<td>Time to transcribe interviews and analyse the data</td>
</tr>
</tbody>
</table>
6.3 Study C: Workshop including Electronic Brainstorming

The goal of Study C was to collect expert knowledge from subject matter experts regarding what anomalies are of most interest to major Swedish organisations related to the maritime domain. More specifically, organisations, such as the Swedish Armed Forces, Swedish Coast Guard, Department of Fisheries Control, Port of Gothenburg, Swedish Customs, Lloyds and the Swedish Emergency Management Agency were all represented. In the study, the participating subject matter experts from the different organisations were asked to list events for which an early warning would be desirable. In order to investigate this issue in an efficient manner, a workshop which included electronically supported brainstorming was chosen. Workshops (Young, 2002) are typically intensive and only last for a few days at most. The workshop can be structured in a way that consensus regarding a topic can be achieved at the end of the workshop. Brainstorming sessions (Young, 2002) most often involve idea generation with the goal to identify as many ideas as possible. The benefit of this type of method is that it allows the opinions of the users to be collected without them being interpreted by the researcher. The workshop (including the brainstorming session) was performed in Gothenburg, Sweden, at Lindholmen Science Park with a total of approximately 25 participants. After the workshop, 6 representatives from potential U.S. partners (e.g., government and universities) participated in a review process. In addition, the Swedish Coast Guard also took part in the review process as they could not attend the workshop that particular day. The review process was conducted to get additional input on the findings of the brainstorming session. The similarities to Study B should be noted, that is, both studies aimed to collect knowledge which will function as alarms to operators. For full details regarding the study the reader is directed to (Laere & Nilsson, 2009).

6.3.1 Procedure

Before the workshop, an intentional choice to focus on “early warnings” was made. We believed that anomaly detection is not a concept used by operators, and thus, “early warning” would be easier to understand. The participants in the workshop were invited via individually worded emails. The ones who did not reply within the time frame were contacted by telephone. The workshop was held during one day, started with a presentation of its purpose and proceeded with a presentation of the current state of maritime domain awareness by a senior expert in maritime domain applications. After the presentation the brainstorming session on “What early warnings do we need in the future? was held. The brainstorming session was performed with the aid of a group support system involving 20 lap-
tops, two projectors, a facilitator, and software supporting brainstorming, categorizing, and voting. The system enabled each participant to simultaneously answer the pre-defined questions via the computer provided to them (i.e., the participants could click on a question and add information). Submitted answers from all the participants were visible at their own work station as well as on the projected screen. That is, the participants only communicated via the group support system (anonymously). Most of the external participants were given individual computers. Project members shared a computer, as well as some representatives from the Swedish Armed Forces, because they were such a large group. To become accustomed to the tool, participants first took part in a 10 minute training session. After the training session the participants had approximately 20 minutes to, via the group support system, brainstorm what early warnings were needed. In this short period, 75 early warnings were identified. A vote to select the most interesting ones resulted in the identification of 31 early warnings. This voting activity was facilitated via the group support system. These 31 early warnings were then discussed via the group support system in more detail with respect to the following questions:

- What information is needed to detect this early warning?
- Where can that information be found (sources, systems, organisations)?
- How can one tamper with this information, and how can it be prevented?
- How can this information be fused (methods/algorithms)?
- What is the added value of fusing compared to the existing situation?

In this comprehensive discussion, over 200 comments regarding these questions were compiled.

After the brainstorming session, the group support system was used to produce a summary report of the comments made during the workshop. After some minor editing, this report was used as the basis of the technical review process in which chosen representatives reviewed the output of the workshop on quality and completeness. In the following section the main results from the workshop are presented.

### 6.3.2 Results

The main result of the workshop consists of the ideas generated during the brainstorming session. In total, 75 early warnings were identified. A vote to select the most interesting ones resulted in identifying 31 early warnings. The most desired early warnings, reflecting the preferences of Swedish stakeholders, concern issues in the following categories (cf. Figure 6.1):
The **tampering** category exemplifies issues which describe an intentional act to hide current activity. The category **owner/crew** relates to interesting characteristics regarding the people connected to the ship. The largest category, **history**, concerns early warnings based on data captured in different registers. **Rendezvous** indicates situations in which, for example, a vessel encounters another object or location, while **movement** is a specific category related to the behaviour of objects at sea. The category of **cargo** includes interesting characteristics regarding goods the ships are transporting. The 31 most important early warnings selected have been discussed in more detail (cf. Table 6.3).
Table 6.3 Example of detail information regarding one of the elaborated top 31 anomalies presented for illustration purposes (extracted from the report generated from the group support system)

<table>
<thead>
<tr>
<th>Early Warning</th>
<th>ownership and flag history: recent change of flag, change of ownership</th>
</tr>
</thead>
</table>
| What information is needed to detect this early warning? | • owner, flag state, other ship data  
  • It is important to determine not just who the owner is but the whole ownership structure. There are 7 levels of ownership from Beneficial Owner (the one who financially benefits from the commercial activity of the ship) to the Operator. Flag changes are not a problem per se, however frequent flag changes denote highly unusual behavior and should be a leading indicator of anomalous behavior.  
  • data in order to have the most recent information in the VMS- fishing vessel register. |
| Where can that information be found (sources, systems, organizations)? | • ship registers, National ship register, Lloyds, Jane's registers?? (if they cover civilian vessels)  
  • All 7 levels are available from Lloyd's Register Fairplay. LRF have data on 154000 merchant vessels and issue the IMO number (unique global vessel ID) on behalf of the IMO. LRF and Janes are owned by the same company |
| How can one tamper with this information, and how can that be prevented? | • flag in corrupt state  
  • As long as the data is from a trusted third party, this is not an issue as it is fusing self reported data (AIS) with validated data (LRF). The added value is the output based on the expertise and the knowledge of the people validating the basic data |
| How can this information be fused (methods/algorithms)? | • compare with data from arrival/customs declarations  
  • compare with intelligence data on allegiances of owners, connections to known terrorist/crime organisations/rogue nations  
  • create models for vessel behaviour depending not only on specific ship and ship type but also on current owner (and crew)  
  • by using search engines like google among the ship databases it is technically possible to fuse the information. Change of ownership in fisheries usually goes together with change of IRCs and external marking. Imported VMS-data from other states are therefore compared concerning vessel ID |
| What is the added value of fusing compared to the existing situation? | • identify vessels that behave as cooperative targets (deception)  
  • The output is then more useful as a decision support tool as it gives the end users not just a mass of information but the RIGHT information at the right time. |

6.3.3 Reflections

The workshop was very successful in capturing a large amount of data during a short time period, mostly due to the built in automatic report functionality in the group brainstorming system. However, what can be seen is that the data gathered lacked some details, and some data can indeed be difficult to understand without its intended context. The main characteristics of the study are summarised in Table 6.4.
Table 6.4 Summary describing Study C. Electronic brainstorming session in the context of a workshop

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Methodology attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>Maritime Surveillance</td>
</tr>
<tr>
<td>Focus</td>
<td>Informing prototype development, work practice of finding anomalies</td>
</tr>
<tr>
<td>Level of analysis</td>
<td>Macro</td>
</tr>
<tr>
<td>Study object</td>
<td>Existing decision-making situation</td>
</tr>
<tr>
<td>Issues investigated</td>
<td>Possible future alerts</td>
</tr>
<tr>
<td>Documentations</td>
<td>Brainstorming notes (the participants own words and ideas)</td>
</tr>
<tr>
<td>Result (output)</td>
<td>Statistics (e.g., votes and number of comments etc.), summary text report,</td>
</tr>
<tr>
<td>Positive aspects</td>
<td>Many different participants from different organisations at the same location</td>
</tr>
<tr>
<td>Level of formality</td>
<td>Formal and structured with possibility of collecting quantitative data</td>
</tr>
<tr>
<td>Requirements</td>
<td>Special group brainstorming software, 20 laptops, projector, facilitator</td>
</tr>
<tr>
<td>Effort</td>
<td>May be difficult to find participants, little time collecting data and less time for analysing</td>
</tr>
</tbody>
</table>

6.4 Reflective Summary

In this chapter we have seen different fusion applications and how they can support human decision-making. From the studies presented, we can suggest that the domain is complex and how such technologies can support decision-making is not obvious. For instance, it is noted that the understanding of the situation picture (typically created with IF technology), on which the decision should be based, is very context dependent (Study A). Study B indicated, for example, a problem with whether or not to support situation vs. impact assessment. Hence, there is a need for methods investigating the relationship between the decision maker and IF technology.
CHAPTER 7

Case Study 1: A Characterisation of a Semi-Automated Fusion Process

This chapter documents the empirical study of a maritime surveillance task in which a semi-automated fusion process is identified and characterised. In particular, the human decision maker’s (user’s) role in the semi-automated process is highlighted. This case study exemplifies the preliminary version of the CASADEMA method (cf. Figure 2.1).

7.1 Background

The fusion process is a central concept in IF. As previously discussed, it has traditionally been approached as a technology matter, with less emphasis on the usage and possible user interaction within the process. As we have seen in Section 3.4.3, the literature documents a number of isolated activities to be carried out by users to refine the process (presented at a high abstraction level), but this does not extend to how users actually function as active components of the process. Also, there is a general lack of empirical user studies. Consequently, this chapter presents an empirical case study investigating a semi-automated fusion process at a more detailed level in terms of the cooperative nature of the process. This investigation and, hence, characterisation is essential, as it can be considered the first step in developing a method for capturing such interactions (cf. Figure 2.1). Furthermore, this case study empirically illustrates the theoretical arguments put forward in Section 5.5 regarding the applicability of a DCog perspective on IF.

The case study chosen here centres on a maritime surveillance tracking task which can be considered a typical fusion environment. The task itself is typical in the sense that it involves the identification and tracking of objects in a dynamic, uncertain environment, with the aid of fusing information from different sensors. This can be considered one of the traditional problems approached within the IF
In addition, the domain of “maritime surveillance” can be considered as typical because it has a history of exploiting various sensor data. Thus, the presented case study can successfully be used to demonstrate a semi-automated fusion process in terms known to the IF community. Moreover, while the overall process can be considered fairly simple, it is shown that this seemingly simple process is indeed dependent on a complex interaction between the human decision makers and the technology they use.

In the following sections the maritime surveillance case study is introduced (cf. Section 7.2) together with a detailed analysis (cf. Section 7.3-7.5) of the activities and information flows involved in identifying and tracking moving vessels which illustrate how machines and human operators collaboratively perform fusion in a highly distributed fashion.

7.2 The Case Study Setup

The following is the description of the empirical case study set up. The procedure below contributed to the preliminary method, as previously illustrated in Chapter 2, Figure 2.1.

7.2.1 Data Collection Methods

The case study is a field study in which the main data collection method was participatory observation (Waddington, 2004; Mank, et al., 2005). This method allows researchers to observe the participants while being embedded in their work environment. The method allows the observer to ask questions and be instructed by the users as they perform their work, thereby increasing the researcher’s first hand understanding of the situation. The observer can form “relationships and participates in activities but makes no secret of an intention to observe events” (Waddington, 2004). In other words, the observer experiences and understands the work setting from an insider perspective. There is thus a trade off between participating in the work setting while at the same time observing it (Patton, 2002). In this study, the researcher had the role of “the new work colleague”. The participants being observed were requested to describe their work as well as provide detailed instructions regarding it to the observer. This method was chosen due to its applicability to the case study domain and its ability to

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19 One type of environment often referred to in IF Handbooks (e.g., Liggins, Hall & Llinas (29009) is situations encompassing a dynamic situation where the goal is to automatically track a number of objects, over time, with the usage of various sensors. The tracking of boats, vessels, vehicles or airplanes are mostly considered in those situations. This type of task is also highlighted by the yearly fusion conference which typically includes special tracks/sessions related to tracking (e.g., FUSION 1998, 2009).
capture field data at a detailed level (when you do not understand you can directly ask questions of the experts).

The focus of the participatory observations was set by the framework of DCog. In particular, the observation focused on capturing descriptions of the different artefacts and their use, as well as capturing the distributed nature of fusion.

**Procedure**

The participants in the study were chosen by the contact person at the maritime surveillance centre. The contact person had received instructions, by the researcher who conducted the study, to select participants with different levels of experience. In addition, the participants should work during different time periods (night/day). The participants had received limited or no prior information regarding the researcher or the study itself.

Each session thus started with a briefing by the researcher regarding the aim and output of the study, as well as how the data would be treated (i.e., integrity and anonymity). In addition, the participants were told that the researcher should be considered as a new member of the team with no prior experience. A total of 5 participants were involved in the study, with an average of three years experience. In practice, the data collection was divided into two steps, distributed over 4 occasions (including a pilot session), and distributed evenly around the clock to allow for different conditions, making a total of 16 hours of observation (cf. Table 7.1).

The first step, introduction, aimed at providing an overview of the work setting. This was achieved through a general information (power point) presentation by the contact person. The presentation included information regarding the organisation of the centre, its history, main responsibilities and overview of the process for monitoring Swedish territory. This was followed by an informal interview regarding the activities of the control room. The informal interview was followed by a tour of the work place. The tour was ended with initial observations of the activities of control room. In the initial observation it was determined that operators positioned at 3-4 (cf. Figure 7.3 for layout of workplace) were of most interest for the study as their task was to create, update and be continuously aware of the “normal picture” and any deviations from it.

The second step (experience the domain), involved sessions of participant observations (Waddington, 2004) with operators working hands on with the system used to capture the overall picture of the area appointed to the surveillance centre. The operators worked primarily at positions 3-4, but had also experience of positions 1-2 and could therefore, in addition, provide valuable insight relevant to those positions (cf. Figure 7.3). The focus of the participant observations was the interaction with the different artefacts and people. During
the observations, a total of approximately 70 vessels were identified and tracked by the team of operators. For complimentary purposes, the possibility to access documentation concerning current work procedures was provided. Field notes (pen and paper) were used to capture work procedures and events during the observations. The field notes were summarised after each session and then verified for correctness by two of the expert operators at the end.

Table 7.1 Overview of study

<table>
<thead>
<tr>
<th>Step</th>
<th>Session</th>
<th>Task</th>
<th>Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Introduction to domain</td>
<td>1 (Contact person)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Initial observation</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Participatory observations</td>
<td>2-3 (Operator)</td>
</tr>
<tr>
<td>3</td>
<td>(see above)</td>
<td></td>
<td>4 (Operator)</td>
</tr>
<tr>
<td>4</td>
<td>(see above)</td>
<td></td>
<td>5 (Operator)</td>
</tr>
<tr>
<td>5</td>
<td>(see above)</td>
<td></td>
<td>6 (Operator)</td>
</tr>
</tbody>
</table>

7.2.1 Data Analysis

The collected data was approached from a DCog perspective (Hutchins, 1995a). The analysis focused on identifying patterns describing how information was propagated between systems and operators involved in the IF process. This way, the distributed nature of the fusion process can be captured. In addition, the following guiding questions were used:

- How is information propagated throughout the system?
- What entities can be identified as contributing to the fusion process?
- What role do the human users have within the fusion process?

As DCog does not include a specific notation to capture and visualise information propagation, the following notation (cf. Figure 7.1) was developed in order to answer the above stated questions.
The descriptions (i.e., definitions) of the concepts displayed by the notation are provided in Table 7.2. These concepts have previously been defined and elaborated upon in Chapter 5, Section 5.3.
### Table 7.2. Glossary of terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artefact (information</td>
<td>Physical or digital element (not limited to a specific physical artefact) that plays a functional role within an activity (involved in the fusion process).</td>
<td>A monitor display and emails are separate entities, although they are found within the same artefact.</td>
</tr>
<tr>
<td>resource)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human (information</td>
<td>A human that plays a functional role within an activity (involved in the fusion process).</td>
<td>A decision maker or operator responsible for a specific task.</td>
</tr>
<tr>
<td>resource)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mediating</td>
<td>The mediating role of humans and artefacts in the propagation of information, a process denoted by the functional relationship between the entities.</td>
<td>An information or human entity can have a mediating functionality of coordination in which they connect different entities.</td>
</tr>
<tr>
<td>Representational state</td>
<td>Knowledge and information represented at specific instances in the conduct of an activity.</td>
<td>A monitor display, a verbal utterance, or a printed label, are all information–bearing structures.</td>
</tr>
<tr>
<td>Transformation</td>
<td>A change in representational states (visual, mental and auditory), when propagated between entities in the conduct of an activity.</td>
<td>A monitor display changes its state in response to an operator's key command. A voice message changes its state as it is picked up by an operator and is represented mentally.</td>
</tr>
<tr>
<td>Social structure</td>
<td>A social structure is a configuration of humans for a specific purpose to achieve a goal</td>
<td>Team working together or other organisational structures.</td>
</tr>
<tr>
<td>Cognitive process</td>
<td>Manipulation (including propagation, transformation) of representational states which are distributed across individuals and artefacts, between (human) internal and external structures, and over time.</td>
<td>Cognitive processes are those involved in memory, decision-making, inference, reasoning and learning, etc.</td>
</tr>
<tr>
<td>Unit of analysis</td>
<td>The functional relationships between entities and the transformation of representational states of information related to the studied process</td>
<td>The fusion process manifested in the Maritime Control Room in which it is distributed over humans and technology.</td>
</tr>
</tbody>
</table>

#### 7.3 The Case Site: Maritime Surveillance

The site of the study was the maritime surveillance centre in Malmö operated by the Swedish Navy, in particular the maritime surveillance and information battalion. The centre was one of six centres distributed along the coast of Sweden (as of 2010 these centres have been centralised). The main task of these centres is to monitor Swedish territorial waters and provide support in the event of naval warfare. With the aid of, amongst others, radar, surveillance boats and the voluntary flight force, vessels are being identified with the purpose of creating a (real-time) updated “situation picture” of the current situation at sea. This “situation picture” basically includes the position and identity of vessels on
Swedish territorial water. The centre in Malmö employs conscripts, sea surveillance leaders, and naval army officers (a total of 66 people were employed in 2006). The centre can be considered to be organised into two areas: (1) a control room surveying the Swedish territorial water which operates 24 hour a day, and (2) an administrative part which only operates during day time. The administrative part typically involves activities such as international cooperation regarding various NATO documents, etc.

More specifically, the operators working in the control room located in Malmö are responsible for surveying an area outside the south-western Swedish coastline, that is, the entrance to the Baltic Sea (cf. Figure 7.2). The main task of the operators is to identify vessels, analyse the situation, and when required, inform the responsible defence agency to take action.

![Figure 7.2 Geographical overview of the entrance to Baltic Sea including number of objects passing](image)

The control room itself is divided into different stations according to responsibility (cf. Figure 7.3 and 7.4). The operators positioned at 1-2 (first line operators) are responsible for identifying each vessel entering Swedish territory (cf. Figure 7.3). Operators working at position 3-4 (second line operators) are in charge of producing and keeping track of the overall “picture” while the operator working at position 5 is in charge of all incoming messages, fax etc (cf. Figure 7.3). The operators at 1-2 and 5 are typically conscripts in training while operators positioned at 3-4 can be civilian sea surveillance leaders. There seems to be a progress between work stations as operators become more experienced. That is, when starting working at the control centre as a conscript, the initial position...
may be at 1-2 or 5 (cf. Figure 7.3), which may be followed after some time with a role as a sea surveillance leader at position 3-4.


This leads to an implicit hierarchy within the control room where operators positioned at 1-2 are more likely to engage in spontaneous conversations compared to operators positioned at 2 and 4. That is, first line and second line of operators are more likely engaged in conversation when the first line of operators needs support (i.e., help in solving a task) or while passing on information to complete the “situation picture”. In other words, a complex cooperation between humans and technology is required to identify vessels, analyse the situation and, when required, inform the responsible defence agency to take action.
More specifically, operators 1-2 work in a high density environment consisting of different kind of vessels, such as ships, freighters, ferries, and even some fishing boats (cf. Figure 7.2). The environment thus includes both objects which are interesting to observe (vessels) and objects which can be classified as “noise” (non-interesting objects). The main interface they work with is displayed in Figure 7.5. The picture in Figure 7.5 illustrates the overview display which consists of vessels positioned over a geographical schematic map. Vessels highlighted in yellow are yet to be identified/confirmed. To identify these objects, a number of surveillance resources, such as radars, optic cameras (day and night vision), AIS (automatic identification system), and VHS radio, are available to the operators (cf. Figure 7.6). Depending on the source used, the object to be identified is assessed with different trust values. That is, if the operator has personally seen the vessel through the optical camera (day or night vision) the vessel is identified with a high level of confidence, and thus, receives a high trust value. Furthermore, to be able to track chosen objects a tracking algorithm is utilised fusion radar data.
Figure 7.5. The Overview display. (A) The operator can click on the different objects to get more information as well as add information (a popup window attached to the object emerges). (B) The operator can change the mode of the display to indicate the tracks of the objects.

Figure 7.6. Exemplification of additional sources to be used to increase the reliability and trust value of the identified object. From the left: Optic camera, radar equipment, surveillance boat, voluntary flight force, and a helicopter

To illustrate the activities of the control room, consider the following scenario: A vessel departing from Saint-Petersburg passes Swedish territory to leave the Baltic Sea in the Sound (between Sweden and Denmark). The vessel is picked up by radar but does not have any AIS data. The team of operators not only needs to identify this vessel, but also be certain that they have made the correct identification. In brief, the following activities are conducted (cf. Figure 7.8):

1. The vessel (object) is automatically registered as it is picked up by radar (shown as plots on a screen). However, the AIS data (the
identification number) which are normally revealed on the overview display, is not present in the above described scenario (cf. Figure 7.5).

2. The **identification** process is started when the operator (position 1-2) manually distinguishes what radar reading is caused by vessels from other environmentally caused radar readings (i.e., “noise”). This is a demanding process which requires significant skill. The identified vessel is classified, in this case as unknown (or when possible associated with the correct AIS information). As the object does not have any AIS data in the above described scenario, the operator needs to use additional information sources situated in the control room to identify the object (cf. Figure 7.6 and Table 7.3). The operator uses different strategies to determine the identity of the object depending on the type of object and situation.

3. The vessel is continuous *monitored* by the operator and, the real-time *tracking* of the identified vessels is carried out by a fusion algorithm that combines information from different radar sensors. Finally, a report of interesting objects is created by the operator and transmitted via different technological equipment to the headquarters (i.e., the authority in charge of all maritime control centres in Sweden).

The outlined process can take from 15 minutes up to 2 hours (or longer) for each identified object. This depends on what information sources are available for the identification of the object. For instance, it was observed that sometimes the operator waits for a vessel to be identified to be within the range of the optic camera to be able to make a positive identification (that is, identification with high confidence/reliability).
Table 7.3. Main artefacts used by operators in the maritime surveillance control room.

<table>
<thead>
<tr>
<th>Main information sources</th>
<th>Description of functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overview display</td>
<td>Main tool which operators interact with to identify and locate vessels. The overview display provides three different modes, depending on the task operators need to perform; the operators can view the original radar data, they can choose to only view located objects, or view the trajectories of located objects. Information regarding the located objects is continuously updated for identification.</td>
</tr>
<tr>
<td>Optical camera</td>
<td>To verify the identity of located objects, a long distance optical camera with day and night vision can be used for visual identification.</td>
</tr>
<tr>
<td>Intranet/Internet/email</td>
<td>Additional sources for identifying and storing information regarding vessels are available to the operators. An Intranet is provided with information about internal routines. The Internet is used as a search engine for additional information, such as weather or the name of a vessel. Each day emails arrive with information regarding the identity of vessels passing the lighthouse.</td>
</tr>
<tr>
<td>Summary report</td>
<td>A sheet of paper containing a summary of attributes the identify vessels is provided by the first line of operators to the second line of operators, to be submitted to various systems (e.g., message equipment and diary, etc.).</td>
</tr>
<tr>
<td>Message equipment</td>
<td>Technology that enables information from the summary report to be transmitted, e.g., to military head quarters.</td>
</tr>
<tr>
<td>Diary</td>
<td>The information regarding identified vessels from the summary report is stored in a special “diary”.</td>
</tr>
<tr>
<td>UHV/VHS Radio</td>
<td>The radio is used as a tool for communication between control room and different vessels. Also, the operators listen in on the communication between different vessels at sea (the names of vessels may be mentioned and this information can be used in the identification process).</td>
</tr>
<tr>
<td>Database</td>
<td>Database containing pictures of different types of vessels. For instance, this database is used to determine what operators see in the optic camera (i.e., a comparison can be made)</td>
</tr>
<tr>
<td>Folder</td>
<td>Collection and storage of incoming faxes and other documents such as permits.</td>
</tr>
</tbody>
</table>

It is the above described process of identification and tracking of vessels which is of interest in this study.
7.4 Analysis and Results

In this section, the field notes from the participatory observations are elaborated upon from a DCog perspective (cf. Section 7.2). The models and descriptions provided are a synthesised view of the observations made during the study. That is, there can be individual differences (e.g., personal preference, experience, etc.) not captured by the illustrations.\(^{20}\)

7.4.1 Walkthrough of a Semi-Automated Fusion Process\(^{21}\)

The following is a more detailed description of the above described process to be used in later analysis. An overview of the observed process is presented in Figure 7.9.

At the beginning of the identification process, the object is automatically picked up by the different radars. The radars provide an echo when it hits an object which is transmitted back to the control room. An echo can thus be created by any objects at sea or be environmental caused readings. These echoes is visualised on the overview display as plots (i.e., dots) (cf. Figure 7.5). By interacting with the overview display, it is up to the operators (i.e., the first line of operators) to manually distinguish interesting vessels from environmentally caused radar readings (noise) on the overview display. The operators expressed that to make this distinction is not always easy.

In addition, the object is automatically picked up by AIS (Automatic Identification System) readings. All vessels are required to have an AIS transponder sending out their identification number. This is automatically visualised on the overview display (shown as a small square with an identification number). Naturally, radar readings which are overlapping with AIS data are judged by the operator to belong to the same object.

When an object is located by the operator (i.e., an item is marked as an located object on the overview screen), it is automatically provided with information such as position, direction, course, callsign (i.e., identification number), time of initiation and updated at, in addition to AIS standard information. Also, an automatic fusion algorithm that continuously tracks the objects is automatically initiated as the object is located.

\(^{20}\) To capture such individual differences one needs to create a set of illustrations at an individual level, which is beyond the scope of this thesis.

\(^{21}\) In this context, “semi-automated” refers to the fact that some of the functions associated with identification and tracking are allocated to humans and some to technology. Hence, the fusion process goes beyond the boundary of the technology itself, to include users

\(^{22}\) In this context, automatically refers to an action not initiated by the operator located in the control room
The fusion algorithm fuses the data (e.g., the position (the coordinates) of echo including the time stamp) provided by the radars and thereby tracks the object. The output of the fusion algorithm can be shown as lines attached to an object, indicating its whereabouts (cf. Figure 7.5, overview display mode B). When an object pass an area with no radar coverage (e.g., behind a small rocky island) and then enters an area with coverage, the tracking algorithm may get “confused” and the located object (the square indicating a located object) may end up at the wrong location. The operator then needs to manually distinguish its right location and move the located object by interacting with the overview screen. The operators expressed that the most obvious misplacement is when an object (i.e., the square indicating located objects) end up at land. Others less obvious situations are when the tracker switch place between objects. These can occur when objects just emerge from the area without radar coverage or the objects come close.

To continue, when the object is located and provided with the automatically generated information, the first line of operators needs to add more information to further distinguish the vessels, such as type, class, name, nationality, type of
identification source (quality of source) and identified on list. This information is
can be added to the object by clicking on it (a popup table emerge which the
operator can interact with). In order to add this extra information the operator
uses additional equipment in the control room, for instance, long distance
camera, the Internet, or a list of identified vessels provided by email (cf. Table
7.3). Mostly, a collection of these sources needs to be utilised to add the required
information. The operators utilise different strategies to determine what source of
information to use to collect the required information. Most of all, the
availability of the sources determines its use. For instance, there is a military
position at a light house which manually (visually) identifies passing objects. The
list of identified objects is, amongst others, emailed to the control room. When
this email arrives it is provided to the first line of operators which can use the list
as a checklist against the current objects within the area of the operators’
responsibility. That way, fill in any missing information. In addition, the operator
can wait for an object to be in the range of the optic camera (with day and night
vision) and that way fill in any missing information. This information can then,
by the operator, be compared to information from the database which stores
pictures and data about previous objects (e.g., vessels or other boats) entering
Swedish territory. The radio is another source which can provide valuable
information (i.e., when captains of vessel talk over radio they use their callsign to
identify themselves). This information can then be used to identify unknown
objects. Moreover, operators usually change the overview display to only show
located targets, enabling them to focus on one target at a time to collect the
required information (cf. Table 7.3 and Figure 7.5).

As part of the identification process, each identified object needs to be
verified (because the AIS information can have been changed intentionally) and
its permission to operate in Swedish waters needs to be checked. A target that
seems suspicious (e.g., a foreign vessel with no right or permit to pass or operate
in Swedish waters) is prioritised and receives special attention. When the target
has been fully identified and double-checked, the most important attributes are
written down in a special summary report which is passed on to the second line
of operators to be transmitted to the responsible agency (e.g., the military marine
headquarters, cf. Figure 7.9). The second line of operators also makes a special
summary (in the form of a PowerPoint presentation) of events during their shift,
to be presented to the one following.
7.4.2 Information Propagation between Humans and Technology

Re-examining the process described in the previous section from a DCog perspective (using a DCog vocabulary) indicates that the process includes much information that is propagated through the system of humans and technology, and many transformations of representational states are identifiable in the humans and the different artefacts used (cf. Table 7.4).

Table 7.4. A summary of human-technology interactions, and representational transformations (cf. Figure 7.5 and 7.11). Each number corresponds to the numbers in Figure 7.4. For the definition of concepts see Section 7.2.1.

<table>
<thead>
<tr>
<th>Mediating information resource</th>
<th>Information propagation and transformation</th>
<th>Supported cognitive processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Overview display</td>
<td>Visualisation of current surveillance situation including objects of interest; radar data is automatically transmitted to be displayed on a map, transforming its representational state, additional information is continuously added to the objects identified on the display changing its representational state</td>
<td>Situation awareness, communication</td>
</tr>
<tr>
<td>2 Optical camera equipment</td>
<td>Visual contact for identification of vessels; the perceived image is transformed to a representation which can, via operators, be associated (through internal structures) with vessels stored in, e.g., internal memory and in the external database</td>
<td>Situation awareness, trust</td>
</tr>
<tr>
<td>3 Intranet</td>
<td>System for storage of knowledge and experience of incidents; internal structures of humans are transformed into an external representation accessible to the operators within the system</td>
<td>Attention, knowledge, communication</td>
</tr>
<tr>
<td>4 Internet</td>
<td>Additional source of information as well as backup system for overview display; information from external sources is transformed into a representation available to the operators in the control room, the information provided is associated (through internal structures) with, e.g., the overview display, transforming its representational state</td>
<td>Knowledge</td>
</tr>
<tr>
<td>5 Message equipment</td>
<td>Recording of attributes of interesting vessels; radar data shown on the overview display is transformed into written messages accessible to people outside the system</td>
<td>Communication, attention</td>
</tr>
<tr>
<td>6 VHS Radio</td>
<td>Tool for communication between control room and different vessels as well as communication between vessels; auditory information (speech) is transformed into a format accessible to other people positioned at a different geographical position, as the information propagates through the artefact, it may be transformed (due to disturbances etc.), when associated with internal structures and, e.g., the overview display, the representation transform again</td>
<td>Situation Awareness</td>
</tr>
<tr>
<td>7 Database with pictures of vessels</td>
<td>Database containing identified vessels; information stored in the database is transformed into external representations accessible to others</td>
<td>Knowledge</td>
</tr>
<tr>
<td>8 Folder</td>
<td>Collection and storage of incoming faxes and other documents;</td>
<td>Memory,</td>
</tr>
</tbody>
</table>

23 In the view of Hutchins (1995a, 2001) the concepts mentioned would be considered cognitive processes emerging from the interaction between humans and artefacts
<table>
<thead>
<tr>
<th>9 Diary</th>
<th>Document containing the most important incidents (identified objects); the text report is transformed into a representation independent of time, accessible to others</th>
<th>Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Equipment controlling the radio</td>
<td>Equipment controlling choice of VHS channel; <em>internal structures of an operator is transformed to an representation which can be accessible (noticeable) for operators in the system, by controlling the radio, the artefacts changes its representational state</em></td>
<td>Attention</td>
</tr>
<tr>
<td>11 Communication unit</td>
<td>Facilitation of communication among operators; <em>the artefact mediates communication and as information propagates through the artefact, from one person to another, it may be transformed (due to disturbances etc.)</em></td>
<td>Communication, awareness, trust</td>
</tr>
<tr>
<td>12 Telephone</td>
<td>To gain information and feedback on actions; <em>internal structures are transformed to auditory information which is propagated and transformed by the phone, e.g. in case of disturbances on the line</em></td>
<td>Communication</td>
</tr>
<tr>
<td>13 Report</td>
<td>A summary of identified vessels facilitate communication among the team of operators; <em>information from the overview display is transformed, via the operator, to a temporal representation which enable shared access among the operators</em></td>
<td>Attention, communication</td>
</tr>
<tr>
<td>14 Fax</td>
<td>Provides information to the system; <em>a physical representational state of information accessible to the operators</em></td>
<td>Attention, communication</td>
</tr>
<tr>
<td>15 Email</td>
<td>Information from weather reports and lists of identified objects are sent by email; <em>knowledge (i.e., internal structures) is transformed to a representation (text) allowing exchange of information between people inside and people outside the system, as the text information is associated with internal structures of the operator receiving the information, the representational state changes</em></td>
<td>Attention, communication</td>
</tr>
<tr>
<td>16 Additional equipment: TV</td>
<td>Possibility to display additional information about current situation; <em>information provided by the equipment transforms data from the overview display into meaningful information</em></td>
<td>Situation awareness,</td>
</tr>
<tr>
<td>17 Additional equipment: Computer with internet</td>
<td>Additional computer equipment; <em>knowledge is transformed/exchanged between individuals inside and people outside the system</em></td>
<td>Situation awareness, communication</td>
</tr>
<tr>
<td>Operator 1-2 (first line of operator)</td>
<td>First line of operators in charge of identifying and tracking vessels; <em>Human mediated propagation of information between (one or more) information sources, changing its representational state</em></td>
<td>Knowledge, memory, situation awareness, reasoning</td>
</tr>
<tr>
<td>Operator 3-4 (second line of operators)</td>
<td>Second line of operators in charge of overall situation; <em>Human mediated propagation of information between (one or more) information sources, changing its representational state</em></td>
<td>Situation awareness, knowledge, memory, reasoning</td>
</tr>
<tr>
<td>Operator 5</td>
<td>Operator in charge of dealing with incoming faxes and providing this information to the second line of operators; <em>electronic information transforms to paper based text information accessible to the operator, and changes representational states as it is associated with internal structures and positioned at different location in the control room to be accessible to the second line of operators</em></td>
<td>Memory, reasoning, attention</td>
</tr>
</tbody>
</table>
For example, multiple radar data from external resources outside the control room are automatically transformed into visual information, in terms of radar plots on an overview display (cf., Figure 7.10).

![Diagram](image)

**Figure 7.10** Transformation between artefacts and humans, which changes the original representational state. See Figure 7.1 and Table 7.2 for description of the notation.

These radar plots on the overview display are then accessible to the first line of operators who need to interpret the radar plots and locate vessels. When an object is located, a target tracker is automatically turned on. In other words, the information automatically transforms into different representational states as it is propagated between artefacts, without human intervention (cf. Figure 7.10).

As the operators receive information from other sources (e.g., Table 7.4: no. 14, 15, 16, 5, 6, 9,), summarise it, and use it to identify objects on the overview display, the information is propagated through the socio-technical system, and its representational state changes several times (cf. Figure 7.10). For example, the radio constantly provides audio information to the operators in the control room, and as it is picked up by the operators, its representational state is transformed into the internal representational states of the operators. This information is then added and used to identify vessels on the overview display, again transforming its representational state (cf. Figure 7.11).
Figure 7.11. Examples of transformations between humans and artefacts. A change in representational state occurs as information is transformed from human internal structure to a form accessible to others.

Similar propagations of information are initiated when information from other sources, such as email and fax, is used to identify vessels. In addition, knowledge in an operator’s mind (e.g., internal memory structures) changes its representational state and becomes accessible to others, as the knowledge is entered into the database containing pictures of vessels (Table 7.4: no. 7). Another example is the storage of experiences and knowledge on the Intranet; a change of representational state takes place as internal knowledge is written down and stored in an external format, thus becoming shared knowledge (cf. Table 7.4, no. 3). When incoming faxes and other documents are collected and stored in a folder for easy access, the combined pieces of information (the folder’s contents) form a new representational state, and, as new documents are added, its representational state is again transformed (cf. Table 7.4: no 8). Similarly, as information is added to the located objects on the overview display, the representational state of the individual object is transformed, as well as the representational state of the overview display (cf. Figure 7.12).

Figure 7.12 Change of representational state within an artefact. Each time a fax is added, the folder changes its representational state. Similarly, each time new information is added to the overview display its representational state changes.
In summary, the overall fusion process consists of changes in representational states as information is propagated through the socio-technical system, including both operators and technology. The identified trajectories exist between artefacts, within artefacts, and between artefacts and humans. Firstly, some transformations of representational states occur when information propagated between artefacts is facilitated by humans. That is, when additional information resources (email, optic camera, fax, database, Internet, airplane) are actively requested by the operator to complete the fusion process, for example, when an optic camera is used to identify unknown objects visible on the overview display. Here, the human operator functions as a mediator between the optic camera and the overview display, linking the two artefacts, and thereby enabling transformations of representational states (cf., Figure 7.12). Also, the user mediates the continuous refinement of the fusion process, such as aiding the target tracker when an object is lost (e.g., when a tracked target is located on land, the user moves the target to the right position at sea). The human operator actively requests additional information sources, and thereby initiates the mediation of information by enabling different resources to connect/be fused (cf. Figure 7.9). This exemplifies that the trajectories of information flow between humans and artefacts.

![Diagram](Image)

**Figure 7.13** Humans mediate information propagation between optic camera and overview display, enabling changes in representational states. The same process is initiated for email, fax, database etc.

In addition, some of the information resources are automatically introduced into the process via operators, without being requested, for example, when audible information from the radio is automatically perceived and added to the overview display. Thus, the human operator automatically mediates a change in representational states. In other words, input to the fusion process can either be actively requested by operators or automatically mediated by them.
Secondly, some transformations of representational states occur when, for instance, information resources are automatically included in the fusion process, via technology without human intervention, allowing different technologies to connect/be fused. For example, multiple radar data are automatically transmitted to be shown on the overview display (cf. Figure 7.14), which can then be interpreted by operators. This can be referred to as automatic input. Also, some representational states are continuously refined in the information process, for example, when the target tracker automatically follows identified objects at sea, and thereby changes the information on the overview display.

![Figure 7.14 Automatic technology mediates transformation of representational states.](image)

### 7.4.3 The Human Role in a Semi-Automated Fusion Process

Using a DCog perspective, some of the cognitive processes involved in the interaction can become visible (cf. Figure 7.15). For instance, the identification of a vessel partly involves the automatic fusion of radar data and AIS information, and partly the cognitive process of recognizing an object as a foreign vessel. Recognising an object as a vessel that needs to be tracked is one of the most important human cognitive processes that contributes to the IF process. The recognition of an object can be triggered by several things. For example, external information sources, such as email, draw the operators’ attention towards a specific kind of vessel, or their own previous experience and knowledge (memory) bringing the operators’ attention to a specific vessel. To recognise an object is a top-down process in which different features of the object are matched by the operators, using information from external information sources or internal knowledge.
The actual memory capability is distributed between humans and artefacts. More specifically, the folder provides an external resource that extends human memory, and transforms individual memory into external memory shared by all the operators. The folder is also an object of interest in the fusion process and, as such, it not only draws the individual user’s attention but also facilitates shared attention. In addition, situation awareness (general understanding of the current situation) can trigger the operators’ attention towards a specific vessel.

Reasoning about the provided information is also needed in order to determine whether or not the located object should be processed further. Here, the operators’ ability to reason refers to transforming the information provided on the overview display to the operators’ internal structures where the information can be related to past experiences. As an example, email, telephone, and optic camera provide additional information that presents the operator with the possibility to trust the identity of the object (i.e., the information on the overview display). The information is then added as a property to the identified objects.

The decision-making activity involves the issue of whether or not the information should be added to the communication unit for further access by other organisations. Moreover, a key part of the process is communication.
mediated by several artefacts. Some equipment specifically provides a means of communication, such as the Intranet and VHS Radio. The equipment mediates communication and facilitates a common understanding of the current situation, that is, **situation awareness**.

Notably, while situation awareness is facilitated by the overview display, other artefacts are equally important, for example, optical camera, Intranet, and VHS radio. Situation awareness, then, is a process distributed among the operators and the artefacts they interact with, and there is no one individual or artefact that holds a complete situational picture. This means that situation awareness is not centralised in one single display, or in any other resource, since no resource on its own can provide meaning to the current situation. Even though the overview display summarises the current situation, the way it is perceived within the context of its use, emerges from the interaction between several entities, which leads to an understanding of the current situation, it is thus a property of the socio-technical system. This is exemplified by the fact that each 12 hour period is summarised in a PowerPoint presentation which, to some degree, allows knowledge and situation awareness to be shared between co-workers (but it is not made accessible to other responsible organisations). It should be noted that the PowerPoint presentation is not only a report on identified vessels (a “summary report” including objective attributes such as name, position etc., describing identified vessels), but is also intended to capture the operators’ subjective impressions of the current situation.

### 7.5 A Characterisation of a (Long time frame/low Intensity) Semi-Automated Fusion Process

The identified fusion process includes a significant amount of information that is propagated through the system of humans and technology. Further, many transformations of representational states are identifiable in the users and the different artefacts used. The identified trajectories exemplify the cooperation between operators and technology in the creation of the “situation picture” (i.e., the identification and tracking of objects), and thereby indicate that the actual fusion process extends the boundary of a single technological artefact. The distributed and sometimes shared cognitive processes are also visible in the information flow of this socio-technical system in which processes are distributed across time and space, and many of the resulting representations facilitate different shared cognitive processes. In this context, without the operators and their cognitive processes, the identification and tracking of objects would not be possible.
More specifically, when looking at the analysis some distinct patterns emerge. For instance, the human is as an *active component* in the fusion process, and *different categories of input* can be identified (i.e., automatic and requested). More specifically, we have also seen, in the previous sections that users actively requested information from additional information sources when necessary, while other information sources were automatically perceived by the operators (e.g., auditory information from the radio was automatically perceived by operators, without an explicit request, providing situation awareness, in other words, the radio provided a context for the information shown on the overview display). The importance of the radio as an information source for the fusion process is generally not acknowledged in IF research.

Furthermore, this study illustrates that interaction between operators and IF technology, in many cases, goes both ways, that is, the operators support the IF process and similarly, the technology supports the operator. Even with the extension of Level 5 (i.e., the User JDL model) it can be argued that there is still an emphasis on how the human can contribute to the fusion process rather than how the fusion process supports the human cognitive processes. In this case study, a number of cognitive processes are extended and include both humans and technology, thereby supporting the human. The overall findings can be captured in the following tenets (cf. Chapter 11 for a more extended discussion):

- The identified fusion process cannot be reduced to the automatic processing of a specific technical system alone; rather, the fusion process emerges from the interaction between technology and its user(s), and extends beyond user(s) and artefact(s).
- The operators have been identified as an active part of the fusion process. More specifically, different types of input to the fusion process have been identified and can be (roughly) categorised as actively requested or automatically perceived ones. Also, *human and technology mediated* transformations occur which can be *automatically* or *actively* initiated. Furthermore, external and internal information sources have been identified.
- An equal consideration of manual (operator) as well as automated instances of fusion in the same overall IF process in the sense that it does not distinguish between representational states and/or transformations in technology or operators has been enabled.
- A number of cognitive processes, such as situation awareness, memory, attention, etc., have been identified as resources of the IF process and these processes are distributed among the operators and the artefacts they interact with.
To conclude, these *empirical* findings further reinforce the *theoretical* arguments put forward in Section 5.5 regarding the applicability and the implications of a DCog perspective for characterising the fusion process.

### 7.6 Reflective Summary

In this chapter we show that the fusion process cannot be reduced to the processing of a specific technical system alone; rather, the fusion process, in many cases, emerges from the interaction between technology and its user(s), and extends beyond user(s) and artefact(s) (thus confirming the theoretical argument put forward in Section 5.6). That is, despite the lack of research regarding the role of users in the fusion process, we show in this chapter that the operator can be a significant part of the process as an active component. By being a part of the process we not only show that the operator contributes to the fusion process, but also that the fusion process is interrelated to the cognitive processes identified. We thus further establish the role of users within IF research. In addition, this case study provides valuable contributions, in terms of notation, definitions and overall approach, leading to the developed method, explained in Chapter 9. This case study thus illustrates the output to be expected from CASADEMA.
CHAPTER 8

Case Study 2: Interdependencies between Decision Making and Information Fusion

This chapter documents the empirical study of an airport traffic control task in which the interaction between operators and IF-based decision support is identified. In particular, how the operators actually use the technology in the support of decision-making is highlighted. The case study thus identifies the interdependencies between decision-making and IF. In addition, the study exemplifies the intermediate version of the CASADEMA method (cf. Figure 2.1).

8.1 Background

As presented in previous chapters, a limited amount of information exists on how IF actually supports decision-making beyond, for example, the situation awareness model and the OODA loop (cf. Section 3.2). Therefore, the aim of this empirical case study is to capture how IF technologies, and the fusion processes in particular, support human decision-making in practice. This investigation and, hence, characterisation are essential because it is considered a further important step in developing a method for capturing interactions within semi-automated fusion processes. In addition, this case study empirically illustrates the theoretical arguments put forward in Section 5.5 regarding the applicability of a DCog perspective on IF.

The case study chosen to illustrate the connection between human decision-making and IF centres on a task in an air traffic control room in which an operator has to direct airplanes for landing. The task involves a number of interrelated decision-making activities based on the output from a suite of decision support tools (including a fusion application). The choice of the case study site is based on its ability to complement the previously presented case study (cf. Chapter 7), as well as its representativeness as a typical fusion
environment. In comparison to the previous case study (cf. Chapter 7), the Air Traffic Control task represents an undertaking in which the operator can be considered a main fusion node, in addition to the specific fusion application installed. Also, the focus of this study is the emergent decision-making process when interacting with the decision support. Moreover, this case study complements the previous one in terms of its ability to represent an environment which requires quick decisions, that is, decision cycles about 3-7 minutes (compared to the maritime surveillance task which can have a decision cycle ranging from 15 minutes to 2 hours (or longer). It should be highlighted that the case study was also chosen because it represents an existing, fully working system, in addition to being a none-defence system. This should be seen in contrast to what is commonly presented in the IF community.

In the following sections, the case study is presented in more detail. A description of the case site, as well as the result of the study and its subsequent analysis are elaborated upon.

8.2 Case Study Setup

The following is the description of the empirical case study set up. This can be regarded as the application of the second version of the method, contributing to the intermediate method as illustrated in Chapter 2, Figure 2.1.

8.2.1 Data Collection Methods

The case study presented here is a field study using iterations of direct observations and informal conversational interviews (unstructured interviews) as data collection methods (Patton, 2002). Direct observations involve a description of "the setting that was observed, the activities that took place in that setting, the people who participated in those activities, and the meanings of what was observed from the perspective of those observed" (Patton, 2002, p. 262). An informal conversational interview is an open-ended approach in which the researcher has the flexibility to choose the direction of the interview. That is, the questions in the interview are not predetermined but based on the intermediate context. Combining direct observations and informal conversational interviews has proven to be especially beneficial; the observations can inform the interviews

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24 The object of this case study can be considered a typical fusion environment in terms of its dynamic nature, the multiple moving objects tracked by sensors, and the actual presence of a real fusion application (i.e., the conflict system) integrated with the real time decision support.

25 Most research presented in within the IF community concerns various prototypes for future applications. Studies of fully working system are not that common. Also, the defense domain is the most developed domain using IF technology, see Chapter 3 for more information.
since the questions are not required to be specified beforehand. As Agar (2008, p. 157) argues, “I also know that if you watch people doing things, you learn something you can’t get by just talking with them, although, you can’t learn much unless you do talk to them before, during, and after the event”. These particular methods were chosen because the environment of the case study does not allow the subjects to be disturbed due to critical safety reasons. With this approach, observed phenomena can then be discussed in the informal interviews (cf. similarities to participant observations utilised in Case Study 1 (cf. Chapter 7)).

The focus in the observations and interviews was set by the DCog framework. More specifically, the observation focused on captured data so that the different artefacts and their use could be captured, which is a similar aim to that of Case Study 1 (cf. Chapter 7).

**Procedure**

Participants were chosen by the contact person at the Arlanda Air Traffic Control Centre (ATCC), according to their availability and willingness to participate. Each participant had received prior information from the contact person (through intranet), and at the start of each session they were briefed by the researcher, conducting the study, regarding the aim and output of the study, as well as how the data would be treated (integrity and anonymity). A total of 5 participants were involved in the study. Two participated in regular, informal interviews and three in sessions combining both observations and informal (unstructured) interviews. All of the participants can be considered experts, having between 5-15 years of experience. Moreover, all of the participants had experience instructing students who were training to become air traffic operators. In practice, the data collection was divided into three steps distributed over 8 sessions, during a 4 week period for a total of approximately 40 hours (cf. Table 8.1).

The first step (“getting to know the domain”) involved online documents describing the Arlanda ATCC domain (1 session). A description of the different departments at Arlanda ATCC and the different system used in the air traffic control centre can be found on the Swedish Civil Aviation Administration (Swedania) homepage. These documents were studied as background material to obtain an overview of the domain. In fact, one of the requirements when performing informal interviews is “that you know enough about local talk to actually conduct an interview” (Agar, 2008, p. 139), which underlines the importance of studying available information.

The second step (“getting to know the overview”) involved informal (unstructured) interviews with team managers at the ATCC (Session 2-3). The

26 In Swedish: Luftfartsverket (Swedania)
Chapter 8 Case study 2

The aim of the interviews was to confirm the information collected from the documents (first step) and gain more in-depth knowledge regarding the specific tasks of the ATCC. Hence, the purpose of the interviews in this step was to define a common ground for carrying out observations in the following step. Approximately 3 hours of interviews were conducted.

The third step ("getting hands on experience") involved sessions of observations and interviews with operators working hands on with the systems used for controlling and coordinating airplanes in the sky (about 35 hours duration, i.e., sessions 4-8). The focus of the observations and interviews was to capture how the systems were used to support the decision-making process. The observations and the interviews were performed iteratively. In each step, and after each session, field notes (taken with pen and paper) were summarised.

### Table 8.1. Overview of Study

<table>
<thead>
<tr>
<th>Step</th>
<th>Session</th>
<th>Task</th>
<th>Participant</th>
<th>Role of Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Document study: &quot;getting to know the domain&quot;</td>
<td>Online Documentation</td>
<td>Informant</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Interview session: &quot;what does TMC stand for?&quot;</td>
<td>Team manager 1 ATC</td>
<td>Gate-keeper (training informant)</td>
</tr>
<tr>
<td>3</td>
<td>(see above)</td>
<td>Iterations of observations and interviews: &quot;how is the airplane in the sky monitored and controlled?&quot;</td>
<td>Team manager 2 ATC</td>
<td>Gate-keeper (informant)</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Iterations of observations and interviews: &quot;how is the airplane in the sky monitored and controlled?&quot;</td>
<td>Operator 1 ATC</td>
<td>Key-informant (stranger-handler)</td>
</tr>
<tr>
<td>5</td>
<td>(see above)</td>
<td></td>
<td>Operator 1 TCM</td>
<td>Key-informant</td>
</tr>
<tr>
<td>6</td>
<td>(see above)</td>
<td></td>
<td>Operator 2 ATC</td>
<td>Key-informant</td>
</tr>
<tr>
<td>7</td>
<td>(see above)</td>
<td></td>
<td>Operator 3 TMC</td>
<td>Informant</td>
</tr>
<tr>
<td>8</td>
<td>(see above)</td>
<td></td>
<td>Operator 4 ATC</td>
<td>Informant</td>
</tr>
<tr>
<td>7</td>
<td>(see above)</td>
<td></td>
<td>Operator 4 TMC</td>
<td>Informant</td>
</tr>
<tr>
<td>8</td>
<td>(see above)</td>
<td></td>
<td>Operator 3 ATC</td>
<td>Informant</td>
</tr>
</tbody>
</table>

### 8.2.2 Data Analysis

The collected data was approached from a DCog perspective (Edwin Hutchins, 1995a). In particular, the data was analysed for patterns describing the usage of the fusion technology so that a connection between human decision-making and...

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27 The roles of the participant can be as follows (Agar, 2008): Informant (a member of the group who provides the researcher with information); Key-Informant (a member of the group whom you develop a special relationship with, i.e., “Rapport” the official term of a good relationship with an informant, p. 137)); Gate-keeper (a member of the group who provides you access to informants, which can, be an official or an unofficial role for a member of the group); Deviant (members at the boundary of the group in a low-status position); Stranger-handler (official/unofficial members of the group to deal with outsiders/visitors); Training-informant (a member of the group who provides new connections, and insights regarding their own work situation).
fusion technology can be made. In other words, the focus in the analysis is, foremost, on the cognitive abilities of the artefacts. Special attention was given to determining how the different information sources are used to support human decision-making. The following guiding questions were used:

- How is information propagated throughout the system?
- What entities can be identified as contributing to the fusion process?
- What role do the human users have within the fusion process?
- What decision support functionality is provided by the different design features of the decision support systems?

In order to answer the questions, the notation (cf. Chapter 6: Figure 6.1 and Table 6.1) developed, in the first case study, to capture activities and processes of the studied environment, was used (cf. Chapter 6). That is, the identified concepts (e.g., entities, transformation, representational states, etc.) defined the focus of the analysis.

### 8.3 Case Site: Air Traffic Control

The site of the study was the Arlanda ATCC, which is one of two centres providing air navigation services en route in Sweden. The ATCC is located at Stockholm-Arlanda Airport and the main task of the operators is to maintain well-ordered traffic and prevent collisions. In other words, their task is to direct aircraft in maintaining a safe distance between them in all directions. More specifically, the main task of the operators in the centre is to (1) continuously provide pilots with necessary instructions and authorisation and (2) keep track of the aircraft’s journey, and position in the air. A complex cooperation between the operators, advanced technology and work methods is needed to achieve this goal.

Arlanda ATCC is divided into two departments: the Area Control Centre (ACC) and the Terminal Control Centre (TMC), which are co-located (cf. Figure 8.1). This is special since most other countries separate the two. The TMC is responsible for airplanes approaching Arlanda airport while ACC is responsible for those at a higher altitude. The altitude of the airplane therefore determines which department is in charge. Additionally, the tower at Arlanda (the Terminal Control Area (TMA)) is responsible for airplanes on the ground, and 'take off'.

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28 This focus is shaped by the nature of the fusion process studied. That is, a fusion process in which the operator is supported by the output of the fusion application. The fusion application is also one component of a larger decision support system.

29 Due to the nature of the studied environment, questions in case study 1 were not applicable as this application operators interact with the output of a fusion process.

30 This question were added due to the nature of the task studied (cf. Case Study 1)
This study involved both the ACC and TMC departments since they are situated in the same control room (centre), and perform similar tasks.

The operators in the room work at different stations (cf. Figure 8.1). Each station is responsible for a specific sector based on geographical region and altitude. In addition each station, has an executive and a planner role, which can be acquired by the same person or two people depending on the current workload. The role of the executive is to direct and talk to the pilots on the radio. The planner is responsible for coordination issues which involve communicating by the telephone. Stations and sectors are opened and closed depending on the number of airplanes in the area, which also determines if one person or two people are needed for the executive/planner role.

In addition to the operators working at the different stations, there is a technical supervisor in charge of the technical systems (radar, radio, etc), a watch supervisor whose responsibility encompasses the operative work (including coordination with military units, etc), a tactical supervisor responsible for tactical decisions (opening/closing of positions, etc), and an administrative assistant (organising more personnel, etc.). There are approximately 30 operators, distributed over 16 stations, working each day (ten in the ATC and six in the TMC). Not all the stations are used at the same time. Clocks in the room indicate the current time both in the Swedish time zone and GMT (the standard time used in all technical systems and when communicating with airplanes).

In order to be able to perform their jobs, the operators need to heavily rely on the information provided by the computer systems (cf. Figure 8.2 and 8.3). They have no direct perceptual access to the environment they control. However, events on the ground can affect the situation in the sky (e.g., depending on the
amount of snow on the landing strip, the planes can be “on hold” in the sky, which thus needs to be implemented by the operator). In 2005, a new set of systems was introduced in the control room, dramatically changing the work. Before this change, all information regarding a specific plane was written down on paper strips. Now, this information is presented on the decision support system displaying airplanes (Information Display B in Figure 8.3). The new system is considered better than the old one, because it enables a different set of possibilities, such as sending certain information requests electronically, which previously had to be communicated via the radio or the telephone.
lists such as the approach sector list, etc. and the search flight plan function (for a schematic overview, see Figure 8.4).

A schematic overview of the technologies used is illustrated in Figure 8.4. In addition, a description of the main artefacts used is found in Table 8.2. It should be noted, however, that this is a general description; adaptation to the work station can be done if and when required due to the specifics of that sector (including personal preferences).

![Schematic layout of a work station](image)

**Figure 8.4** Schematic layout of a work station (cf. Figure 8.2 and 8.3).

**Table 8.2** Main artefacts used by the operators in the ACCT.

<table>
<thead>
<tr>
<th>Main source information</th>
<th>Description of functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information display A</td>
<td>The display is mainly used as a passive information source, that is, the operator only monitors the information for use in making decisions. Information includes weather data (2D image and text reports) and access to electronic flight strips.</td>
</tr>
<tr>
<td>Information display B</td>
<td>The display is considered to be the main screen showing the current state of the airplanes. That is, the screen is a map which displays all the aircraft currently being tracked and is used to direct and control them. The operator actively interacts with the display, e.g., to change values and numbers (i.e., heading and altitude) attached to specific aircraft. Operators are thus responsible for updating the status of the aircraft. The information on this display is based on the transponder (radar) on each airplane transmitting its position, and information from a database of flight plans (in addition to the information provided by the operator).</td>
</tr>
<tr>
<td>Information display C</td>
<td>The display is used as both a passive and an active information source. That is, the operator both monitors and interacts with the display. Most of the information shown on this display can also be accessed</td>
</tr>
</tbody>
</table>
through information display B. Information includes the approach sector list and pre-activation list as well as the possibility of searching flight plans.

**Radio**
This information source allows the operator (executor) to interact and communicate with the aircraft shown on information display B. The radio is the most important tool for directing the airplanes to their correct position in the air.

**Telephone**
This information source is mostly used for the coordination of activities between sectors. It is foremost the planner who uses the telephone to coordinate with other sectors and airports. If a sector has an airport, the operator needs to call it to communicate the arrival time of approaching airplanes landing at that airport (small airports do not have the same system as Arlanda; the information therefore needs to be passed on via the telephone).

**Medium range conflict warning system**
This is an automatic fusion application indicating conflict of planes (i.e., when two planes are too close). The operators are usually already aware of situations alerted by this system. The conflict system is only used at ACC, since in TMC the aircraft are supposed to be close (they are about to land), so the system warns for every airplane in the sector. The conflict system is based on fused radar data transmitted by the airplane.

The process which is of interest for this study is how to direct a plane, approaching Arlanda Airport, through a sector.

### 8.4 Analysis and Results

In this section, the empirical data from the study is elaborated from a DCog perspective (cf. Section 7.2.1). The models and the descriptions are a synthesised view from the observations made as well as of the participants’ experience in the study. That is, there can be individual differences (e.g., personal preference, experience, etc.) not captured by the illustrations\(^{31}\).

#### 8.4.1 A Walkthrough of a Semi-Automated Fusion Process

The general observed process can be described as follows (this process is thus repeated over and over as planes pass different sectors). This description of the process is to be used in later analysis, described in the following sections.

At the beginning of the process (cf. Figure 8.5), airplanes to be directed are automatically picked up by radar and made visible to the operators on an overview display (i.e., information display B). That is, each airplane has a

---

\(^{31}\) To capture such individual differences one needs to create a set of illustrations at individual level, which is beyond the scope of this thesis.
transponder (radar) transmitting their position. This information is visualised as a radar blip together with a label on a schematic map of Sweden with sector areas indicated (e.g., the sector which the operator is currently in charge of is marked as a grey sector) to be accessed by operators. The label includes information such as a free text field (for the operators to use), flight ID, altitude, destination, weight, altitude declared, and speed. Some information is automatically included from other information sources, for example, the flight plan and radar, while other pieces of information need to be added by the operator (this information can also be accessed through the “approach sector list” which includes airplanes currently in the sector).

![Diagram](image)

**Figure 8.5** Simplified overall observed fusion process (not including individual differences). Arrows indicate information propagation between different entities, during which the representational sates of the information are also transformed.

Next, the process of directing and tracking a specific aircraft starts when an operator takes responsibility for it. The colour of the labels facilitates this process, that is, the labels are marked with different colours depending on their position relative to the operator's sector. A grey label indicates aircraft which are of no interest to the operator. A black label with a blue flight ID indicates planes about to enter the sector, while fully blue labels indicate for airplanes which the

---

32 This includes an automatic tracker which tracks the geographical position of the plane
operator needs to take responsibility. When the operator takes responsibility for an airplane, its label turns black. The operator can now access all the information attached to the label, for example, flight plan declared and notes made by operators.

The overview display (information display B) also has boxes called “SIL” in each compass direction which indicate approaching airplanes from that direction. This information source can be used as a planning tool (if the map is fully zoomed in for instance, the SIL can be used to keep track of incoming planes not currently visible on the map). Similarly, there is a “Pre-activation list” indicating airplanes approaching the sector within 10-30 minutes. When a scroll bar appears, the operator knows there will be an increase in density of airplanes, that is, in the words of one operator “now there will be much work to do”. One of the operators also explained that when the transponder code emerges in the pre-activation list, the airplane will soon enter the sector, and information about that airplane will then be found in the approach sector list.

When an operator takes responsibility for an airplane, the next step is to decide in what direction to guide it through the sector. To be able to make this initial decision the operator needs to manually fuse information from many different sources.

For instance, a “weather radar” (information display A) shows current weather radar data (2D image) on top of a simplistic geographical map (the coastline and lakes). This aids the operator by indicating possible thunder clouds which will affect airplanes in that area. If there are many such clouds, the operator knows that many pilots will request a change of course to avoid the area. The operator can also provide this information to the pilot on request. In addition to the weather radar, the operator also has the current weather report in text, which provides information not represented on the 2D image, such as wind direction, air pressure, and so on. This information is of interest because the air pressure can be used in the directing of airplanes (the pressure determines the speed at which the planes can land/take off). The weather report is automatically updated, which is indicated by the box turning blue for about a second. Each weather report is given a name. The operator also has access to the previous weather reports, enabling changes in weather to be detected.

Another source of information which can be used to determine the correct direction is the electronic flight strips (information display A). These indicate the airplanes about to take off from Arlanda airport. A green triangle means that the airplane is about to take off and a rectangle around the flight ID signifies that the airplane will affect the sector represented by the work station. This information is used to indicate an increase in the density of airplanes in the sector. If there are many aircraft about to take off, the operator must ensure that the required space is available, for example, by directing airplanes away from that area. This
information is mainly used by the TMC department as a planning tool. The information is provided by the tower at Arlanda dealing with the airplanes on ground.

Another information source which needs to be considered when directing airplanes is restricted airspace, since there can be areas at certain altitudes within the sector which the airplane cannot cross. Restricted areas can, for instance, be declared during weapons firing exercises by the military. A yellow area indicates that the military has “borrowed” the airspace for training exercises. If the operator would like to route a commercial airplane through that area, he needs to coordinate with the military. Blue areas indicate an open airport. For the operator, this means coordination with that airport is necessary.

Sometimes when a better overview is necessary to enable a decision regarding direction to be made, zoom functionality can be used. This means that either one of three pre-set zoom levels or a free zoom, where the operator adjusts the zoom level by dragging a bar, can be used. Whether the pre-set or the free zoom is used appears to depend on personal preference rather than the current task.

To order to fine tune and test different directions which can be given to an airplane, the operator can add a directional line (prediction line) to the airplanes to see their future positions in, for example, 3 minutes (information display B). This is used to determine if there is a safe distance between aircraft. In addition, this line can be attached to moving airplanes to determine real-time distance.

Another support the operator can use when deciding on direction for a specific airplane is to hover the mouse pointer over the corresponding label. When this is performed, a blue line indicating the corresponding airplane’s flight plan is displayed. If the operator presses a button on the mouse, the line becomes green, yellow, or red. The colour indicates the degree of a collision risk with another plane. Thus, green indicates no risk while red indicates that the reported flight plans are too close to each other or cross.

Information stored in Folders can also be used as additional source of information sources, since they contain details regarding, for instance, special routines and a glossary of airplane types and companies. Other paper-based information sources include details on the upcoming traffic situation, providing a diagram with the number of airplanes expected at specific times. This information can, for instance, help operators mentally prepare for an upcoming increase in workload. Furthermore, this information is used to decide whether or not there is a need to open a “planner” position next to the operator working as the “executor”.

Similarly, different handbooks are available for the operators. These are not positioned in close proximity to the operators at their workstations, but rather, in a centralised place on one bookshelf so that only one location needs to be
updated. These books contain the specifications of different restrictions, routines, and regulations.

An important source of information that should not be forgotten is to overhearing colleagues’ conversations. It was observed that the operators use the proximity between stations to talk to colleagues at other sectors instead of using the radio or telephone. Operators reported that they can easily hear information which is of interest to them in the conversations of other colleagues. This is facilitated by the fact that the stations responsible for neighbouring sectors are also close to each other in the control centre.

Additional information can also be provided by the supervisor who is the receiver of information such as new military restriction areas, airplanes on photographic missions (e.g. photos for Google earth) and runway changes. Such information is passed on to the operators verbally by the supervisors walking around the control centre talking to them when necessary.

In other words, all of the above information sources need to be considered by the operator in order to determine a course of direction for specific planes.

Thereafter, the decision regarding the direction of the airplane needs to be implemented. Using the radio, the operator can thus implement the decision, that is, instruct the pilot to take a specific heading. The operators estimate that they spend 50% of their time talking with the pilots while the remainder is spent on interacting with the technical systems (and coordinating with other sectors, airports). The radio is accessed through a headset.

In order to keep track of the directions given to the pilots of the planes, the operator continuously update the altitude value in the label to the given one.

The operator can also intentionally highlight a label in either yellow or lime. Depending on what colour is used, the highlight is either visible only to the operator himself (executer) or to both the operator and his colleague working in the same sector (planner).

When the airplane reaches the end of the sector, the activities need to be coordinated with the next sector to ensure it is all right to direct it on a certain heading for handover to the next sector. This is mostly done over the telephone. Alternatively, the operator can interact with the labels by sending “white values” (hand over proposal), an automatic (quiet) communication allowing the operator to send requests to other sectors, for example, to change the altitude of an airplane. This simplifies the task as it removes the need to communicate over the telephone.

When an airplane is leaving the sector, its flight ID becomes brown once it has left completely; the entire label’s change to a full brown colour depends on when the next sector takes responsibility for the airplane. However, after a certain time, the change occurs automatically.
8.4.2 Information Propagation between Humans and Technology

A re-examination of the overall fusion process (cf. Figure 8.5), described in the previous section, from a DCog perspective shows that it includes much information that is propagated through the system of humans and technology, and many transformations of representational states are identifiable both in humans and the artefacts used (cf. Table 8.3).

Table 8.3 A summary of information propagation and representational states. An overview of the artefacts mentioned used can be seen in Figures 8.3 and 8.4.

<table>
<thead>
<tr>
<th>Mediating information resource</th>
<th>Information propagation and transformation</th>
<th>Supported Cognitive process</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Information Display A</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weather radar (2D visualisation)</td>
<td>Visualisation of current cloud status; <em>weather radar data is automatically transmitted to be displayed on a simple geographical map</em></td>
<td>Situation awareness</td>
</tr>
<tr>
<td>Weather reports (current, previous): textual information</td>
<td>Visualisation of current weather status; <em>weather radar from multiple sensors is automatically transmitted and displayed in text format</em></td>
<td>Situation awareness</td>
</tr>
<tr>
<td>Electronic flight strip; graphical textual representation</td>
<td>Visualisations of airplanes about to take off from Arlanda; <em>database information (text information) automatically transmitted and displayed in text format together with visual enhancements</em></td>
<td>Situation awareness</td>
</tr>
<tr>
<td><strong>Information Display B</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overview display (Geographical Map displaying location of airplanes)</td>
<td>Visualisation of geographical map together with location of airplanes (with labels), current sector responsibility, restricted areas; <em>radar data is automatically combined with database information (labels) and displayed on geographical map.</em></td>
<td>Situation awareness, reasoning,</td>
</tr>
<tr>
<td>Airplane identification (Radar blip and Labels)</td>
<td>Text summary (which changes colour) of airplane identification information including flight plan; <em>database information is automatically transmitted and displayed as textual information at the location of the radar blip</em></td>
<td>Situation awareness,</td>
</tr>
<tr>
<td>SIL (sector identification list)</td>
<td>Text information regarding approaching airplanes from different directions; <em>radar data and flight plan data is transformed into a representation of accessible to operators</em></td>
<td>Situation awareness,</td>
</tr>
<tr>
<td>Conflict system (fusion application)</td>
<td>Warning system of airplanes on collision course; <em>flight plan database information together with radar data information are used to determines conflicts</em></td>
<td>Situation awareness,</td>
</tr>
<tr>
<td>Zoom (pre-set in 3 levels or free)</td>
<td>Functionality to change the level of detail of the map; <em>the tool transform the representational state of the overview display changing the properties of the representation</em></td>
<td>Situation awareness,</td>
</tr>
<tr>
<td>Notepad</td>
<td>Recording attributes of vessels of interest; <em>radar data together with AIS data shown on overview display are transformed into written messages</em></td>
<td>Situation awareness,</td>
</tr>
<tr>
<td>Prediction line</td>
<td>Line on radar blip to display direction of airplane for 1-5</td>
<td>Situation</td>
</tr>
</tbody>
</table>

136 | MARIA NILSSON Capturing semi-automated decision making
The identified trajectories of information flow and the changes of representational states exemplify the interdependencies between the human and technology, and make visible the semi-automated nature of the fusion process. The distributed and sometimes shared cognitive processes (e.g., decision-making, situation awareness, reasoning, etc.) are visible in the information flow of this socio-technical system in which processes are distributed across time and space, and many of the resulting representations facilitate different shared cognitive processes. In this context, without the operators and their cognitive processes the directing and tracking of airplanes would not be possible.

The airplanes are represented in multiple instances throughout the socio-technical system. Firstly, there is a change of colour in the labels...
representing the airplanes as they approach the sector. The different colours correspond to different representational states as information regarding the airplane is propagated through the system (cf. Figure 8.6). As Figure 8.6 indicates, the colours can either change automatically (technology mediated transformations) or by the operator’s interaction (human mediated transformations). The information propagation can be explained as follows.

A grey label indicates airplanes which are of no interest to the operator. A grey label automatically turns black (with a blue flight ID), when an airplane is about to enter the operator’s sector. The black (with a blue flight ID) label automatically turns fully blue when an airplane enters the sector. A blue label indicates an airplane for which the operator needs to take responsibility (i.e., an airplane which the operator needs to direct safely through the sector), and hence, the label changes colour to black after the operator interacts with it. The user can now interact with the label and update the information regarding the airplane keeping track on the headings and altitudes given to the pilot. That is, the representation (label) is continuously coordinated with the operator’s internal mental representation ensuring that there is a mapping between what is internally represented and externally represented. By continuously keeping information externally represented, the information load on put on operators can be decreased, and the reliance of the system increase.

A brown label indicates an airplane which has entirely left (this change depends on when the next sector takes responsibility for the airplane, however, after a certain time, the change happens automatically).
The operator can intentionally highlight a label in either yellow or lime. This is often done as a reminder of some kind in which the operator externalises an internal representation. The meaning of an airplane which is highlighted can be different depending on the operator performing the highlight.

If a white label appears up on the operators’ screen, it is an indicator that the other sector wants the operator to take care of an airplane, even though it is in “the wrong sector”. That is, it has not yet reached the sector so that the colour changes automatically giving the other sector access to interact with the label. This is also known as “silence communication”. It is denoted silence since the alternative would be to call the other sector via telephone. By sending a white value, the other operator can respond to the request when possible. In other words, technology mediated coordination between operators between different sectors occurs. That is, as the representational states change (e.g., colour), the properties of the representation change (e.g., operator can interact with the label).

Similarly, in addition to the information on the labels, the airplanes are also represented in the format of tabular data. As illustrated in Figure 8.7, the representational state of an airplane changes as it moves within the sector.

![Figure 8.7 Changes of representational states](image)

Figure 8.7 can be explained as follows:

The electronic flight strips indicate the airplanes about to take off from Arlanda airport. A green triangle means that the aircraft is about to take off and a rectangle around the flight ID signifies that it will affect the sector represented by the work station. “SIL” in each compass direction indicates approaching airplanes from that direction (i.e., airplanes having a grey label cf. Figure 8.6). There is a “Pre-activation list” indicating airplanes approaching the sector within the next 10-30 minutes. One of the operators also explained that when the...
transponder code emerges in the pre-activation list, the airplane is about to enter the sector, that is, information about that airplane will then be found in the approach sector list. This information is then automatically transformed and changes its representational state as the airplane reaches the sector. Now it is represented in the “approach sector list” (cf. Figure 8.6: blue label). It should be noted that there is no need for human interference since the information is automatically transmitted without the operator’s interaction, which should be compared to the changes in representational states of labels.

This is however the typical procedure, sometimes the technology does not function as predicted. For instance, at one occasion, during the observations, the airplanes did not emerge in the pre-activation list. The reason was that the electronic strip system (Information display A) did not work in the tower at Arlanda. This is considered a serious event since the operator is unable to know what airplanes had taken off (as this is the initiating event, cf. Figure 8.7). That is, they cannot direct airplanes safely in the air. The operators working in TMC thus had to, “trick activate” labels from the pre-activation list manually, a procedure which can be found in one of the handbooks. Consequently, all traffic to Arlanda had to be stopped for 20 minutes so there were time for the operator at TMC to “trick start” the labels manually so airplanes which were about to take off could in fact do so. During this incident, Arlanda initially received a “0 rate” (as determined by aviation headquarters in Brussels) which closed the airport for the aforementioned 20 minutes. Afterwards, Arlanda could open with a reduced landing rate (which specifies the number of aircraft allowed to land per hour). This is considered a rare event and has only occurred once before.

8.4.3 A Real-Time Decision Making Process Emerging from the Fusion Process

In addition to the identified fusion process, a decision-making process emerges in the interactions between the operators and the technology used. The operator creates the structure of the decision process itself, because the suite of technology does not actually provide any guidance regarding in what order to perform different activities. The emerging decision-making process is thus characterised by real-time, and dynamic decision-making, shaped by the evolving decision situation. The basic process is illustrated in Figure 8.8, and elaborated in Figure 8.9. The identified decision process (cf. Figures 8.8-8.9) is based on the usage of the design features provided by the decision support. Hence, Table 8.4 describes the transformation of representational states and thus the role of the artefacts within the decision process.
As illustrated in Figure 8.8, making a decision and managing the decision-making process (including its decision-making activities) involve a continuous process of interacting with, and monitoring the decision support. More specifically, in a simplistic view, the operator interacts with the decision support to implement different decision-making activities and monitors its effect (cf. Table 8.4). This way, the decision-making process and the activities it includes are distributed between the human and the technology, and can be captured in the interaction between the two of them.

### Table 8.4 Overview of decision-making activities

<table>
<thead>
<tr>
<th>Mediating information resource</th>
<th>Information propagation and transformations</th>
<th>Emergent decision-making activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Information Display A</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weather radar: 2D visualization</td>
<td>Visualisation of current cloud status; <em>weather radar data is automatically transmitted to be displayed on a simple geographical map</em></td>
<td>Adjusting, Exploration, Anticipation</td>
</tr>
<tr>
<td>Weather reports (current, previous): textual information</td>
<td>Visualisation of current weather status; <em>weather radar from multiple sensors is automatically transmitted and displayed in text format</em></td>
<td>Grounding</td>
</tr>
<tr>
<td>Electronic flight strip: graphical textual representation</td>
<td>Visualisations of airplanes about to take off from Arlanda; <em>database information (text information) automatically transmitted and displayed in text format together with visual enhancements</em></td>
<td>Grounding</td>
</tr>
<tr>
<td><strong>Information Display B</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overview display (Geographical Map showing location of airplanes)</td>
<td>Visualisation of geographical map together with location of airplanes (with labels), current sector responsibility, restricted areas; <em>radar data is automatically combined with database information (labels) and displayed on geographical map.</em></td>
<td>Progress tracking, feedback</td>
</tr>
<tr>
<td>Airplane identification (Radar blip and Labels)</td>
<td>Text summary (which changes colour) of airplane identification information including flight plan; <em>database information is automatically transmitted and displayed as textual information at the location of the radar blip</em></td>
<td>Progress tracking</td>
</tr>
<tr>
<td>SIL (sector identification list)</td>
<td>Text information regarding approaching airplanes from different directions; <em>radar data and flight plan data is transformed into a representation of accessible to operators</em></td>
<td>Anticipation, Exploration</td>
</tr>
<tr>
<td>Conflict system</td>
<td>Warning system of airplanes on collision course; <em>flight</em></td>
<td>Feedback,</td>
</tr>
</tbody>
</table>
When considering the two concepts, monitoring should not be misinterpreted as a passive activity. Rather, it is very much an active and complex which is performed in the interaction with technology. Interaction, in this case, highlights the activity of managing and dealing with the decision-making process required to take a decision. An act of interaction can either be (1) triggered by

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34 Passive in the terms of a data-driven monitoring activity

35 This is similar to the observation made by Vincent, Mumaw and Roth (2004) who argued that monitoring involves more than just sensation, perception, and attention. Also problem solving and workload regulation is very much a part monitoring.
the decision support itself, (2) triggered by some internal processing of the operator (i.e., an intended action), or (3) by other environmental attributes (e.g., a manager telling the operator to take a specific action).

As illustrated in Table 8.4, “Monitor” and “Interact” activities can be divided into a number of possible, isolated decision-making activities which can be identified in the usage of the different design features of the decision support. In other words, by observing the usage of the decision support and classifying the different observations into categories, a decision-making process emerges. This underlying process is illustrated in Figure 8.9. What can be seen in the figure is a decision-making process characterised by a constant assessment of the decision. Additionally, flexibility is included in the different activities which allow the operator to let the decision evolve along the current situation. The arrows in Figure 8.9 represent our current best understanding of the likely relations among the decision activities based on the data from this case study.\footnote{Future work could involve validation of the model and assess its generalisability.}

![Figure 8.9 Illustration of the main activities involved in the identified real-time decision-making process](image-url)

It should be noted that the activities are not listed in any particular order, and the decision-making process can consist of all or just a few of the outlined activities, depending on the current situation. The decision activities outlined in Table 8.4, as well as in Figure 8.9, are described as follows.
**Anticipation**

Before the initiation of the decision-making process, the operator can be provided with an advanced warning that an activity, such as directing an airplane through the sector. By analysing the information from the decision support as well as the current decision situation, the operator can be provided with warnings, and hence, the possibility to mentally prepare for an upcoming demanding situation (cf. Table 8.4). The operator mentally prepares to deal with an approaching situation, which involves a lowering of the surprise factor. In this way, the operator is thus given an advance warning of a peak in decision-making which will lead to a high mental workload.

This advanced warning could be triggered by *implicit* design features in the decision support (unintentional by its designers). For instance, the scroll list in the pre-activation list can indicate an increase of workload since the mere emergence of a scrollbar provides information. That is, not only the data in the list is used in decision-making but also the change in the representation of the data (a simple table to one with a scrollbar).

Warnings can also arise due to *explicit* design features in the decision support (intentionally incorporated by its developers). For example, the emergence of the transponder code in the pre-activation list is used as an indicator of an increased workload, since the list includes approaching airplanes. The electronic flight strip can also be used in a similar way. The information in the flight strip (i.e., list of airplanes about to take off) is used as an indicator of an increase in density of airplanes in a sector. If many aircrafts are about to take off, the operator has to ensure that the required space is available, for example, by directing airplanes away from that area. Another example is the weather data. If there are numerous thunder clouds, the operator knows that many pilots will request a change of course to avoid the area. The operator can then avoid requests from pilots by not directing the airplane in the typical way. In addition, operators can know from experience that a particular time and day may be more demanding and that there will be an increase in workload. All of the above examples give the operator a chance to prepare, in different ways, and to avoid future unwanted situations. This activity of anticipation is thus distributed between external and internal structures (i.e., between the operator and the technology).

**Initiation**

The activity of initiation captures the start of the decision-making process. The trigger for making a decision is usually initiated by a design feature in the suite of technology used (i.e., the decision support), demanding an action to be performed by the operator. As described above, airplanes have a label in a specific colour (black) to indicate they are approaching the sector. When an operator takes
responsibility for a label (airplane), the operator changes its colour to blue, which starts the decision process (cf. Figure 8.6 for more details about the change of representational states). In other words, the operator is now responsible for directing that specific airplane through the sector.

**Adaptation**

In order to obtain an understanding of the current situation, operators monitor and interact with the different design features of the decision support, and create their own mental picture of the situation, that is, an act of sense-making. As the word emphasises, this is not a passive process. To exemplify, operators change and move the labels attached to the radar blip all the time. This is often done to prevent labels being put on top of each other, since the operator would not be able to read them. However, this could also help the operator be more spatially aware of the current situation since this gives them a sense of the spatial location of the airplanes which helps improve their understanding of the decision situation. Another feature utilised to understand the situation is to highlight labels in, for example, yellow. This way, the operator can mark interesting objects.

In addition, one important part of understanding is assessment. The operator checks the decision according to the current situation by asking the question: have the parameters changed since I made the decision? Furthermore, one operator expressed that he acts and makes his decisions from the mental picture in his head, not what is presented on the overview map (Information display B). This is, for instance, required when there is a need to integrate the weather radar (the 2D image) (Information display A) and the map on Information display B. In this case, the operator needs to mentally keep the information in his head, as the airplanes do not want to fly in specific areas of the sector. We can thus see that this activity is affected by the explicit interaction possibilities provided by the design features of the decision support. The user activates not only the visual senses, but it can also be argued that the operator utilises the active interaction as a tool to create mental structures in order to obtain an increased understanding of the situation.

**Exploration**

By using the design features provided by the decision support, an operator can plan a course of action, for instance, decide how an airplane can be directed through a sector in the most effective and safest way. This is the stage in the decision-making process when the initial solution to a current problem is considered. Typically, instead of relying solely on a mental model, an operator interacts with the decision support and uses the design features, such as the
directional pointer and heading, to check distance, and altitude, and so on, and that way explore the possibilities (cf. Table 8.4). Exploration is closely coupled with adaptation; to explore the possibilities one needs to have an understanding of the current situation.

**Decision Selection**
When exploring the possibilities (where should I direct this airplane?) operators aim for flexibility. An operator tries to have as much flexibility (i.e., ability to change and adopt the decision) as possible since the situation is real-time, dynamic, and constantly evolving.

One typical strategy used by operators is to divide the decision into blocks, for example, set by geographical or temporal constraints. When an operator does not have a complete solution, he/she can make a decision which covers “one block”. This way of implementing “mini-decisions” makes the decision process more simple and manageable. Furthermore, an operator can look for new information on which to base a decision (cf. grounding, mentioned below). Another strategy is to put a decision on hold, and intentionally wait with implementing a chosen decision until the airplane has passed a specific “reference-point”. This can be, for example, a geographical position or a specific altitude. That is, after a particular point in time, the operator needs to assess the situation and make a decision. The situation can be simpler at that point in time (i.e., a simpler decision-making situation) or it may be a better possibility making the decision that they want to implement. In a sense, the operator tries not to interfere with the environment unless necessary. Moreover, the operator can also see that the situation is stable and a final direction is possible. That is, the operator gives one direction and altitude with the intention the pilot can use that course until leaving the sector. It should be noted that the decision becomes very adaptable and flexible, and can change any second. Usually, an implemented decision strategy is chosen on the basis of the current decision situation in combination with operators’ previous experiences (with the underlying strategy of having several alternatives for decisions).

**Grounding**
The decision activity Grounding occurs when the operator explicitly searches for information, provided by the decision support, on which to base the decision. That is, the operator uses some features of the decision support, for example, the

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37 Interestingly, having geographical constraints for determining when to implement a decision has also been reported in Study B which is a study involving the military application Impactorium (cf. Section 6.3.3).
weather report, as input for decision-making, most often to confirm that the decision in mind is the correct one (cf. Table 8.4).

**Decision Implementation**
The activity Decision Implementation acknowledges the explicit direction of airplanes. It involves communicating with the pilot, via radio, giving instructions regarding, for example, altitude. It should be noted that decision implementation should not be done before planning or understanding. If this were to happen, the operator would only react to a current situation and this can have severe consequences.

**Progress Tracking**
In order to remember the different headings given to the pilot, the operator tracks them by constantly changing the values in the decision support via the main screen. Also, the ability to highlight labels and add more textual information helps the operator to manage and keep track of his decisions. This activity does not involve an explicit assessment of the situation, rather, what is highlighted is the track of the evolving situation. By tracking the situation, the operator can notice when an adjustment to the decision is required.

**Adjustments**
As a situation constantly evolves and changes, a decision most often require adjustments.

**Feedback**
In order to see the effect of a decision, the operator can actively look for feedback. Such a feedback activity then works as a control function, making sure that the decision was implemented correctly, or that the operator has the situation under control, for example, supported by the conflict system application. This application was intended to be used as a warning system for a conflict between aircraft (e.g., an airplane coming too close to another one). However, in practice it is used as a warning for “you have missed a situation”. The system is used as a feedback control to check the operators’ knowledge of situations occurring (in practice, all operators generally already know about all the situations for which the application provides an alarm). This was not the kind of decision activity this design feature was intended to have by the designer of the application. But now plays an important role in the decision-making process.
Handover

The Handover activity determines the end of the decision cycle. This is achieved when an airplane has been successfully directed through a sector and handed over to the next responsible sector. This is visible in the interaction with the decision support as labels changing colour (cf. Figure 8.5).

Coordination

Before an aircraft is handed over, an act of coordination is often required. In the process of handing over an aircraft from one section to another, the operator does not coordinate a specific course for the airplane with the operator at the next section. Instead, the operator would say that the pilot should “report their present heading at frequency ...”. This allows operators to be more flexible in their decision-making and makes it easier for the operator in the next section. The operators thereby do not put themselves in a fixed situation that allows only one decision to be made. In other words, an implicit act of coordination is performed without the two operators actually talking to each other.

8.5 Characterisation of a (High Intensity/Short Time Frame) Semi-Automated Fusion Process

The process of tracking and directing airplanes through a sector is a semi-automated process, performed cooperatively by operators and technology. That is, the operators need to rely solely on the information that the technology provides to track and direct airplanes approaching Arlanda airport. Hence, the fusion process is highly complex and goes beyond the technology itself, to include users. More specifically, the case study illustrates a semi-automated fusion process in which the operator manually fuses most information sources in a highly cooperative nature. Moreover, the case study exemplifies a particularly intensive environment in which decisions are made under high pressure and stress. The process often lasts between 5-7 minutes for each directed airplane. Furthermore, an operator handles several aircraft simultaneously and in cooperation with technology. In particular, the decision environment represents a situation in which operators have to rely on different information sources to access the environment. In the case study the human is a central and active component of the fusion process and different categories of input can be identified (i.e., automatic and requested). Similar to case study 1, operators automatically perceive some information sources without requests being made.

In this context, “semi-automated” more specifically refers to the fact there is interdependency between human performed activities and technology performed activities.
Furthermore, this case study illustrates that the interaction goes both ways (as in Case Study 1); the operators support and even enable the fusion process, and the fusion process supports and shapes the decision-making process. As a consequence, the case study also illustrates the interdependency between human decision-making and the fusion processes. The overall findings can be captured in the following tenets:

- The identified real-time fusion process cannot be reduced to solely the process of a specific technical system or that of a human being, but rather, the fusion process, emerges from the interaction between technology and its user(s), and extends beyond user(s) and artefact(s). The possibilities for interaction thus shape the fusion process.
- The real-time fusion process involves propagations of information through a system of artefacts and operators where changes in representational states can be identified. The representations are also presented in multiple instances which highlight the different characteristics of the format of the representation.
- A real-time decision-making process has been identified by focusing on the interaction between the components of the fusion process. This is an active construction process in which information provided via technology is combined with their own knowledge, and continuously updated.

To conclude, these empirical findings further reinforce the theoretical arguments put forward in Section 5.5 and the empirical findings from Case Study 1 regarding the applicability and the implications of a DCog perspective for characterising the fusion processes. More specifically, these findings not only further our understanding of semi-automated fusion processes and their interdependencies with human decision-making, but can also contribute to the method developed for capturing such interactions (cf. Chapter 9).

8.6 Reflective Summary

In this chapter we have shown, as in case study 1, that the fusion process cannot be reduced to the process of a specific technical system alone, but rather that the overall fusion process, in many cases, emerges from the interaction between technology and its user(s), and extends beyond user(s) and artefact(s). This thus further establishes that the fusion process is, in fact, distributed, and illustrates what can be gained of such an approach. Moreover, the interdependencies between emergent decision-making processes and IF technology, have also been
highlighted. That is, despite the lack of empirical research investigating the interdependencies between decision makers and IF technology, we show in this chapter that it is indeed possible to capture such interdependencies. By focusing on the interaction with the technology, a process in which the operator creates its own dynamic, flexible decision-making process can be captured. As a consequence, additional insights beyond the (static) decision-making models typically used in IF to illustrate human decision-making is provided (cf. Section 3.2). This case study thus provides valuable contributions, in terms of procedure, leading to the developed method. It can be argued that the study illustrates the possibilities of a method such as CASADEMA
CHAPTER 9

CASADEMA: Capturing Semi-Automated Decision-making

This chapter discusses the (practical) lessons learned from Case Study 1 (Chapter 7) as well as Case Study 2 (cf. Chapter 8) and frames them in terms of a method denoted CASADEMA (CApturing Semi-Automated Decision-making). CASADEMA provides a structured way of capturing interactions between decision makers and artefacts in semi-automated fusion processes. CASADEMA is mainly intended as a tool for human factors’ practitioners (or similar experts) working within the IF domain. That means, when presenting the method, a “what should be done” focus rather than “how should it be done” is used. It should be noted that the purpose of CASADEMA is to function as a tool for describing and analysing phenomena (as opposed to designing systems). In the following, we provide the background to the method, the theoretical grounding as well as the practicalities of the method.

9.1 The Development of CASADEMA

In Case study 1 (cf. Chapter 7) and Case Study 2 (cf. Chapter 8) we saw the applicability and usefulness of the theoretical perspective of DCog (cf. Chapter 5) to capture the complex nature of fusion processes.

In practice, Case study 1 was the first empirical application of the framework (cf. Figure 2.1 for overview of the development process). More specifically, reflecting upon the conduct of Case study 1 in term of both the practicalities of performing the study (cf. Section 7.2), as well as the output the study (cf. Section 7.5), there are valuable methodological lessons to be learned. In

39 The word “method” is chosen to emphasise the transition from DCog as theoretical framework to a method which includes a systematic step-by-step approach for capturing interaction. In this context, a method is seen as a regular and systemic way of accomplishing an end.
general, there are aspects (developed) during the conduct of the case study which worked well and others which need further improvements (cf. Table 9.1). As illustrated in Table 9.1, there were important considerations for Case study 2 in terms of, e.g., the choice of data collection method and analysis. For instance, it was noticed that the specific interrelationship between human decision-making and the fusion process was only captured to a limited extent.

Table 9.1 Lessons learned from Case Study 1 that were implemented in Case Study 2

<table>
<thead>
<tr>
<th>Component of Case Study 1</th>
<th>Issue</th>
<th>Consequence</th>
<th>Improvements in Case Study 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure</td>
<td>No predefined overall procedure existed before the conduct of the study</td>
<td>(a) Difficult to make sure that all relevant information were collected (b) difficult to know what to look for</td>
<td>Case Study 2 follows a similar structure as Case study 1 with an additional step to structure data collection</td>
</tr>
<tr>
<td>Choice of data collection methods</td>
<td>Participants had received no prior information to the participatory observations</td>
<td>Participants were initially unsure of the role of the researcher and why the researcher was present</td>
<td>Provides information the contact person can use to better introduce the researcher beforehand and considers alternative data collection methods</td>
</tr>
<tr>
<td>Analysis/Reporting findings</td>
<td>Difficult to conduct analysis and to present the results of the case study</td>
<td>A notation were developed during the analysis phase to visualise DCog concepts (cf. Figure 7.1)</td>
<td>Use of the notation, tables and figures is a focus in Case Study 2</td>
</tr>
<tr>
<td>Applicability of DCog</td>
<td>Limited information regarding decision making activities</td>
<td>The focus of the study or the study object could be the cause of the problem</td>
<td>Includes specific tables and additional analysis questions to the method to capture decision making activities</td>
</tr>
</tbody>
</table>

To continue, reflecting upon the conduct of Case Study 2, in terms of both the practicalities of performing the study (cf. Section 8.2), as well as the output produced in the study (cf. Section 8.4-8.5), there are implications for the final version of CASADEMA (cf. Table 9.2).

In terms of procedure, this case study successfully used the same notation and concepts defined in the previous case study (cf. Chapter 7). In addition, the procedure was modified and the process became grounded in Ethnography (Agar, 2008) to a greater extent. To exemplify, the notion of study subjects having different roles, such as stranger-handler, informants, and so on, is now included. The specific data collection methods used (direct observations and informal interviews), which are considered suitable ones were also included (cf. table 8.5).
In addition, based on the findings of this case study, it can be concluded that in the process of capturing interaction, the decision-making process was captured. Subsequently, information propagation can be used to define emergent decision-making processes, and thus, the interdependencies between human and technology, in addition to capturing a fusion process. This will extend the capabilities of CASADEMA.

Table 9.2. Overview of impactions for CASADEMA

<table>
<thead>
<tr>
<th>Component of case study</th>
<th>Issue</th>
<th>Consequence</th>
<th>Implications for CASADEMA (suggested improvements)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data collection</td>
<td>Direct observation as primary method</td>
<td>Difficult to capture everything in field notes (the interaction is too fast)</td>
<td>Encourage use of recording devices</td>
</tr>
<tr>
<td></td>
<td>Introducing ethnography</td>
<td>Defining the role of the participants provided better judgement of the information provided by them</td>
<td>Keep the grounding of the method in ethnography</td>
</tr>
<tr>
<td>Analysis</td>
<td>Use of notation, tables, and analysis questions</td>
<td>The notation and tables structured the data sufficiently however, the analysis questions are a bit vague</td>
<td>Focus more on the implications of change in representational states</td>
</tr>
<tr>
<td>Report findings</td>
<td>Difficult to write up the analysis</td>
<td>Difficulties to provide specific illustrations/examples of interaction</td>
<td>Encourage usage of recording devices</td>
</tr>
</tbody>
</table>

Furthermore, based on the finding from Case Study 1 (cf. Chapter 7) and Case Study 2 (cf. Chapter 8) it can be argued that CASADEMA, to be able to capture the fusion process as described in this thesis, should be able to:

- capture the fusion process as an emergent property of the socio-technical system (i.e., the cooperative nature of fusion between humans and technology)
- portray human and technology performed activities
- illustrate actively requested or automatically received information sources
- capture (two-way) interaction between entities of the process
- capture passive and active entities of the system
- capture cognitive processes as a resource for the fusion process
Chapter 9 The method of CASADEMA

9.2 Introducing CASADEMA

It is important to state the underlying assumptions of CASADEMA because they guide how the human-technology interaction will be approached. In particular, it is necessary to remember how CASADEMA views DCog, since there are many possible interpretations (Walenstein, 2002). CASADEMA is grounded in DCog as developed by Hutchins (1995a) in the early 1990s (cf. Section 5.1-5.2). In particular, its explicit commitment to study cognitive systems as goal based activity systems, and the focus on propagation of representational states. In addition, the DCog commitment to ethnographic studies and its approach to externalising -thereby also “visualising” (cognitive) processes- have influenced the different parts of the CASADEMA method. The underlying assumptions of CASADEMA have been framed into four cornerstones, which can be described as follows:

Firstly, the socio-technical system is the unit of analysis. The boundary of the socio-technical system is set by the functional relationship between the people and the artefacts that are part of the system of achieving a goal. That is, when looking at interaction one should keep a broad perspective and consider the contributions of both humans and the technology. Taking the overall socio-technical system into account implies that one will not ignore the context in which the interaction exists. More specifically, knowledge and processes are also considered to be distributed within this overall context (which in extension puts less emphasis on creating, e.g., mental models). The fusion process is thus distributed, involving both users and the artefacts they are using. Implicitly, they are treated the same way in the sense that the same language is used to capture processes within technology and humans. The consequence is that both the fusion in technology and the fusion performed by users need to be considered, if one is to capture the complete fusion process.

Secondly, to learn about interaction properties, one needs to study the information flow within the system, and how information changes (i.e., its representational state changes) when propagated among the different resources. This allows for the capture of the interaction properties which cannot be traced to a single individual or artefact within the socio-technical system, that is, properties of the collective behaviour.

Thirdly, a resource is an entity of the socio-technical system involved in the fusion process. A resource can be human or artefact, and it can either be for the overall process or for another resource.

Fourthly, when studying the interaction among the resources of the fusion process, CASADEMA considers the usage of information flow which goes beyond merely investigating the fusion of the data captured in the physical and digital artefacts (e.g., information from a fax or database, a piece of paper with a list of
attributes, etc.). One should also account for the role the artefacts themselves play as cognitive support in the operator’s decision-making process (for instance, a notepad can be seen as a form of external memory). In this way, it becomes possible to obtain a detailed understanding of how the decision maker actually uses the information from the different resources. That is, in practice, CASADEMA cannot only capture interactions between the decision maker(s) and the technology as such, but also how it is used to support decision-making. Thereby, CASADEMA focuses on how artefacts are used and modified to support cognitive processes as well as the fusion process, that is, not only on what an object represents, but also on how the properties of the object are exploited.

In addition to the theoretical influences, the methodological influences of DCog will foremost become apparent when collecting data. For instance, the inspiration from ethnographic studies in DCog has led to CASADEMA being most appropriate for the study of interactions within their context of use. More specifically, ethnography influences the following aspects of data collection within CASADEMA (cf. Agar, 2008).

Firstly, field studies are emphasised as a source of information, that is, one would like to study the IF technology as it exists within its context of use (in contrast to the usage of laboratory studies and simulations). Also, Agar (2008) emphasise that a researcher should aim for direct contact with the subjects being studied (i.e., one should aim for a limited use of secondary reports). Moreover, the researcher should apply the “student/child” metaphor (Agar, 2008). This metaphor implies that the researcher is a learner, and a learner is expected to ask questions and allowed to make mistakes. The practical implication is that when conducting the study the researcher does not always have all the relevant questions specified before the study starts, because there is not enough knowledge at that point of time. For a “student/child”, knowing in advance what questions to ask may be difficult. In extension, one should approach the study environment “as if” one is a stranger to the situation being studied.

The aim of ethnographic studies is usually to describe phenomena, not to change the phenomena of interest. Hence, CASADEMA’s commitment in describing the usage of existing IF technology in which the focus of analysis is on the description of the phenomena.

Moreover, there is an emphasis, in CASADEMA, to have an open mind, that is, although one knows that one should study interaction, the information entities involved may not be clear. Also, having an ethnographic perspective involves an iterative analysis, that is, data collection and data analysis are intertwined.
9.3 Procedure of CASADEMA

CASADEMA consist of three main interrelated parts. While one can view these parts as sequential steps (1-3), they can mutually inform each other throughout the process. For example, it is for instance possible that at some point during step 2 or 3 it becomes apparent that more data is needed, requiring step 1 to be performed again. An overview of the method is presented in Figure 9.1. The main steps are (1) data collection, (2) data modelling, and (3) data analysis. It should be noted that there is no clear distinction between analysing and describing, instead, analysis (and description) is, to some extent, performed iteratively in each step of CASADEMA.

A brief summary of the different steps follows (cf. Figure 9.1).

**Step 1** (Data Collection): The first step involves interviews and observation of decision makers working with IF technology to achieve a goal. The focus when gathering data is defined by the principles of DCog and is on the *process* and *information* level. Appropriate data can, for instance, include a walkthrough of the fusion process and a layout of the decision makers and technologies involved, as well as an identification of the entities, inputs and information flow in the fusion process.

**Step 2** (Data Modelling): The second step involves modelling the data, gathered in the first step, using a specially developed notation illustrating the concepts used in DCog, in terms of cognitive properties and information propagation. The focus is on capturing the flow of information. The information produced is figures and tabular data.
Step 3 (Data Analysis): The third step involves assessing the data from the previous steps. The assessment is performed using a checklist of questions based on the theoretical framework of DCog to identify and characterise the properties of interaction between the decision maker and IF technology in the fusion process.

In the following sections, the above CASADEMA steps are explained in more detail by exploring the different tasks to be completed in each of the different steps.

9.3.1 Data Collection
The first step involves data gathering. In practice, data is primarily gathered by observing the socio-technical system of interest (i.e., in this case the usage of IF technology as it exists in its context of use). Standard data collection methods used in ethnographic studies such as naturalistic observations (Patton, 2002), video recordings, participatory observations (Waddington, 2004), and interviews (Patton, 2002), amongst others, are the recommended tools. In general, two data collection methods should be used in combination to enable the collection of all the relevant data. Depending on what kind of environment is to be studied, some methods can be more suitable than others (e.g., in some safety critical environments participatory observation may not be possible). For a practical discussion regarding data collection the reader is directed to Sections 7.2.1 and 8.2.1.

In order to increase the validity and objectivity of the data captured, it is suggested that recording devices be used when, for example, conducting interviews. This enables them to be transcribed and saved for multiple analyses. It is recommended that at least two researchers study the transcripts and perform independent analyses which can be compared.

In order to obtain the best possible data, it is recommended that, in particular, the role of the study’s subjects be identified (cf. Section 8.2.1 for illustrative examples). This is because the role of the study’s subjects can shape the data provided. The different roles are as follows (cf. Agar, 2008).

- Informant: a member of the group who provides the researcher with information.
- Key-Informant: a member of the group with whom the researcher develop a special relationship, i.e., “Rapport” (Agar, 2008, p. 137).
- Gate-keeper: a member of the group who provides the researcher with access to informants, who can be an official or an unofficial role for a member of the group.
- Deviant: members at the boundary of the group, in a low-status position.
- Stranger-handler: official/unofficial members of the group who deal with outsiders/visitors.
- Training-informant: a member of the group who provides new connections, and insights regarding his/her own work situation.

When collecting data, an outside-in approach is typically used (i.e., start with the overview before going into details). In practice, this involves gathering data at different abstraction levels. In other words, one needs to collect data at the process level and the informational level, as explained in further detail in the following sections.

**The Process Level**

The process level has the purpose of capturing the overall process as it is distributed over the socio-technical system, between decision makers (users) and various artefacts (IF technology, information systems, fax, and computers, etc). This enables the main activities, artefacts and actors to be identified. More specifically, one should tailor the observations, and interviews, so as to collect the following data:

- Present a walkthrough of the process from which the data can be unpacked for steps 2 and 3. Here, a process refers to the overall goal of the task to be completed (e.g., identify all foreign vessels and report to headquarters). This description of the process should typically be in text format (to be later used for data modelling and analysis). Thus, a first detailed perceived description of the activities involved in the IF process can be captured. This task can be accomplished by interviews in which the decision makers verbally explain how they proceed in their work (i.e., what activities are performed and what technology is used).
- Illustrate the process in a figure to identify the overall activities performed by IF process and explain the role of the decision makers. It should be remembered that the process is considered distributed among the components of the socio-technical system. The developed illustration will provide an overview in terms of activities performed. This task can be accomplished by observing the decision makers in how they use the technology.
- Provide a physical layout of the technologies used and a description of their main purpose (i.e., describe their functionality in terms of their support capability with regard to cognitive processes). This will provide the researcher with an understanding of the spatial relationship between artefacts and humans (i.e., this information might explain phenomena
identified later on). The task can be accomplished by observing the decision makers in how they use the technology.

For an illustration of what such tasks, as those described above, the reader is directed to Section 7.4.1 and Section 8.4.1.

**The Informational Level**

At this abstraction level, the process is re-examined in terms of its informational value. The purpose is to detail the previously defined process by identifying what information is propagated through the socio-technical system. In order to achieve this, the following needs to be done:

- **Identify the entities in the socio-technical system involved in the IF process (i.e., humans, artefacts, and IF technology).** The entities should be described in terms of how they are used as information resources by the IF process, which also includes an identification of what cognitive processes they support. In other words, what should be described is their mediating functionality, i.e., the focus is on what is mediated rather than the resource itself. This task can be accomplished by observing the decision makers in their work and studying formal documentation (manuals, etc.). However, the functionality documented in manuals can be different compared to how an artefact is actually used in practice.

- **Identify the various inputs to the IF process (i.e., how is the IF process started), which includes information provided automatically through technology as well as information provided via the decision maker.** Also note the role of the entities, i.e., how they activate the IF process. This task can be accomplished by observing the socio-technical system.

- **Identify the main representational states of the entities in the socio-technical system.** This task can be accomplished by theoretically assessing the different entities in terms of DCog, after observing how the different entities are used to carry out the IF process.

- **Identify patterns of information propagation, that is, identify how information flows between entities, and the changes in representational states.** This task can be accomplished by theoretically assessing the different entities in terms of DC after observing how the different entities are used to complete the IF process.

For illustrations of the kind of data the activities described above can produce, the reader is, for example, directed to Section 7.4.2 and Section 8.4.2.
9.3.2 Data Modelling

In the second step, we provide a notation to formalise the gathered data. This notation is designed to capture the interaction between decision makers and IF technology as they carry out the IF process (cf. Figure 7.1). It enables the identification of patterns of interaction flow (i.e., propagation of information) through the socio-technical system, thus, exemplifying interaction. The concepts identified in the developed notation are described in Table 7.2.

The following sections explain how the notation can be used to characterise the interaction within the semi-automated fusion process, by capturing (1) the trajectories of information flow and (2) human- and technology-mediated transformations.

Identification of Trajectories of Information Flow

Using the information captured at the “informational level”, trajectories of information propagation can be identified. The purpose is to characterise the properties of interaction by identifying information flow. In order to achieve this, one needs to:

- Visualise the information propagation using the developed notation (cf. Figure 7.1). This task can be accomplished by theoretically assessing the information gathered in the previous step.

The reader is directed to Figures 7.10 - 7.14 and Figures 8.6-8.7 for examples of such information trajectories.

Human and Technology Mediated Transformations

Specific transformation patterns emerge within the trajectories. These patterns display machine fusion and human fusion. One needs to analyse the trajectories of information propagation to identify patterns such as:

- Transformations of representational states between artefact-artefact. This is an information flow between two technical artefacts in the socio-technical system, and typically exemplifies the automated parts of the fusion process.
- Transformations of representational states between artefact-human-artefact. This can be a human decision maker connecting two different

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40 Other models, such as the JDL model do not have the same level of detail as the developed notation, nor the possibility to both capture interaction in terms of “human fusion” and “machine fusion”. Moreover, there is no formal agreement upon notation or developed visualisation capturing the essence of DCog.
entities within the socio-technical system, which typically exemplifies parts of the process which require a user.

- Transformations of representational states between human-artefact. This typically exemplifies parts of the process in which a decision maker uses internal knowledge (structures) as a resource to refine the IF process.

These transformations can be identified by classifying the transformation patterns according to the above provided classes.

### 9.3.3 Data Analysis

The purpose of the third step is to understand the nature of the components of the IF process, and the interaction among them. In particular, this step involves the researcher re-examining the models developed in the previous step to identify properties of the interaction. The properties of the interactions emerge when considering the purpose of interaction. Some of these properties are obvious; however, some are more “hidden” and go beyond the data stored in different artefacts. More specifically, the researcher needs to examine the different connections in the created models, together with the text descriptions (or tables) of the artefacts, for patterns. These patterns can characterise different interactions and, hence, an identification of the properties of the interaction has been made. The overall guiding questions for identifying such properties are as follows:

1. What additional property is added (or removed) by changing a representational state?
2. What role does an information resource provide for the overall process and the interacting resources (e.g., humans or artefacts)?
3. In what way is information transferred between humans and technology?

By answering the above questions, interaction properties (e.g., feedback, communication, dividing decisions, escalating stop) can be identified. These interaction properties can thus be classified, and thereby capture the distributed and dynamic nature of emergent processes, such as the fusion process or real-time decision-making ones. The reader is directed to the following sections for detailed illustrations regarding what such questions can reveal:

- For question 1 see, e.g., Section 7.4.2
- For question 2 see, e.g., Section 8.4.3
- For question 3 see, e.g., Section 7.4.2 and 8.4.2
9.4 Reflective Summary

This chapter has presented the CASADEMA method, from a practical point of view, in terms of the underlying theoretical assumptions as well as procedure (i.e., a step-by-step instruction).

Considering the basics of CASADEMA, what sets it apart from other methods typically used in IF (cf. Section 4.1) is foremost its theoretical grounding. By using a DCog perspective (which is a theoretical framework explain the nature of human cognition) in particular, the underlying structure of user activities can be explained and accounted for in the fusion process. In addition, having an explicit theoretical grounding is particularly beneficial, because the identified data can thus be interpreted in light of the theory, in order to reveal the components of the fusion process and the broader cognitive context in which it occurs. In particular, if the data that are collected are insufficient to determine the cause of every event, the data can be viewed in the light of the theory and thus have the possibility to provide additional insights. Furthermore, the goal, to identify interaction properties, sets the method apart. The aspects that make the method special are (1) its definition of interaction, (2) the focus on representational states and trajectories of propagation to visualise cooperation between humans and technology, (3) the possibility of putting less emphasis on internal phenomena, such as mental models, and (4) the utilisation of a notation to illustrate representational states.

By identifying interaction on such a detailed level, one is provided with the ability to capture the cognitive mechanism of supporting decision-making with IF.
CHAPTER 10

Discussion

This chapter discusses the implications of the findings of the thesis, in terms of the individual case studies as well as the overall developed method (CASADEMA).

10.1 Extending the Boundary of the Fusion Process

In this thesis we have not only put forward theoretical arguments regarding the applicability of a DCog perspective for explaining fusion processes (cf. Section 5.5) but also further reinforced the arguments by providing two empirical case studies (cf. Chapter 7-8), and realised the perspective in the format of a practical method named CASADEMA (cf. Chapter 9).

More specifically, one of the most important implication when having this DCog perspective is that the fusion processes are considered to be highly distributed, both between several human operators and various pieces of technology (cf. Figure 10.1).

Figure 10.1 Illustration of a fusion process including humans, artefacts and the environment.
The fact that the fusion processes, utilised in the maritime surveillance control room (Case Study 1) as well as in the air traffic control room (case study 2), are complex socio-technical systems involving humans and technology, both transforming and mediating information in the fusion process, points to the equal importance of humans and technology, as they independently would not be able to fulfil the goal of the fusion process described. That the fusion process extends beyond the boundary of technology is reinforced by the fact that external resources continuously affect the outcome of the process. Actually, human users have here been identified as active components in the IF process, that is, the operators’ aid, or in fact partially implement, the fusion process by refining the output and collecting more information when required. All of these points illustrate that the fusion process indeed extends beyond the automatic technological fusion functionality. We also see that human decision-making and the fusion process are highly interdependent.

More specifically, in the case studies discussed in this thesis, the technology components investigated can be categorised as operating at, first and foremost, JDL Level 1 (i.e., identification and tracking). However, taking a distributed view on the fusion process (i.e., including both humans and technology), the outcome can also be classified as contributing to situation assessment and awareness, that is, Level 2 in the JDL model. This illustrates that the (technological) system might have been developed to have level 1 functionality, but once human users (with their background knowledge, inference capacities, etc.) are involved, as a component of the overall system, level 2 functionality is also provided, to some degree. This fact has also been highlighted by Blasch (2006) in Figure 3.6 in which level 1 refers to machines and levels 2/3 denoted humans. The JDL model, as such, does not take this into account, and in that sense does not capture the full extent of IF processes emerging from the user and the (technical) system. Other systems which contribute to, for example, situation awareness (situation assessment) are also not accounted for. Even with its various extensions, the JDL model (cf. Section 3.2) does not explicitly address or examine the interaction between users and IF technology.

Moreover, it has not yet been sufficiently recognised in the IF literature that the interaction between operators and IF technology should be viewed as a two-way interaction, that is, the users support the IF process and similarly, the technological system supports the user (as demonstrated in the two case studies presented in this thesis). Although the ways users affect fusion processes have been identified, the relationship between the technological system and the user has not been defined as a two-way interaction (cf. The JDL model in Figure 3.5). Consequently, the contributions of the system to the user’s reasoning and the contributions of the interaction with other systems are therefore usually not taken into account.
In contrast, the two case studies presented in this thesis have highlighted the fact that (and how) cognitive processes are distributed between humans and technology, both contributing to the IF process. Situation awareness, for example, is a process (or an outcome) distributed among the group of operators and the artefacts they interact with, rather than the output of a specific artefact, such as an overview display (cf. Case Study 1, Chapter 7). Interestingly, it has been argued that “[a]ll too often, IF engineers gather user information needs and start building a system without developing in the interaction, the guidance, or the planned role of the users” (Blasch, 2009).

We believe that the chosen examples, discussed here, indeed represent many – although certainly not all – real-world cases of information fusion where human operators interact with each other and various technological tools. In this thesis, it is argued that in acknowledging the human user as a part of the system as well as other technological/nontecnology artefacts, we obtain a more accurate picture of the fusion process.

10.2 A Change of Perspective to IF as Decision Support

In this thesis, we have argued for a decision maker’s point of view when describing IF systems (cf. Section 3.4). Indeed, we propose that IF systems should be explicitly classified as decision support (cf. Section 3.3.1). Moreover, we have also illustrated, in this thesis, that such a decision-making point of view is possible in empirical studies and that such studies can produce valuable information (cf. Chapters 6-8). We believe that having a more explicit focus on decision support can have important consequences for the IF community.

As an example, current trends within the IF community aim at extending the concept of the IF process to include humans as well, e.g., Akita (2002); Blasch, (2009); Blasch & Plano, (2003); Bossé et al., (2007), but presently lack the means (beyond ‘level 5’) to reach and create this ‘user perspective’. Taking a combined decision support DCog perspective, as presented in this thesis, implicitly provides such means and has therefore the potential to support current trends in the community.

Furthermore, applying this user perspective and treating IF systems as DSS would be likely to ensure the effectiveness of the system. As IF systems become increasingly more advanced, only use ever more advanced sensors to optimise the system, is no longer sufficient. According to Bolia, Vidulich, Nelson, & Cook (2007) argue: “[t]he fact that an increase in the number of sensors and the complexity of the network uniting them has engendered an increase in the amount of available data does not necessary mean that officers using that data will make better decisions” (p. 191). It becomes clear that there is a need to approach IF from another perspective, the decision support perspective.
Treating IF systems as DSS also provides a natural top-down perspective. As previously discussed, research in IF has been driven by the JDL model and, thus, until recently, from a bottom-up perspective. This has led to numerous studies focusing on the lower levels of the JDL model. In contrast, treating IF systems as DSS can provide a top-down perspective (thus, in extension, providing a holistic view of the IF process), increasing the research conducted at the higher levels of the JDL model, especially those dealing with user issues. In other words, having a top-down perspective would put the focus on questions such as who should be supported by the system, and what information is needed to reach a particular decision. Thus, the needs and requirements of users would be considered before deciding what data can be fused and what aspects within the data are needed to support a decision.

Although there are benefits in considering IF systems as DSS, there are also challenges. Firstly, and perhaps the most challenging, is the need to have a thorough understanding of the decision-making process, in order to build an effective DSS. Indeed, “maximally effective decision aiding requires the problem representation in the decision aid to reflect the problem representation and cognitive processes of the decision maker using the aid” (Zacharay & Ryder, 1997, p. 1244). To this effect, the present thesis shows that, by using a DCog perspective (in the form of CASADEMA), we can better capture decision-making processes and thereby enable a decision support perspective (cf. Chapters 6-7 and 9).

Also, the two disciplines of IF and DSS have to this point developed more or less independently. However, in order to apply DSS approaches in the field of IF, there is a need to inform and combine the research results of both areas. This is especially relevant since a closer interaction between both disciplines can easily be of mutual benefit. We have argued in Chapter 3 that the IF community can benefit from information on how to provide a user perspective when designing IF systems. Similarly, the DSS community can benefit from research within the IF community. Wiederhold (2000), for example, argues that an efficient information system which supports decision-making needs to present information from the past, present and future. In other words, it needs to integrate databases with simulations and models which is precisely the aim of IF. Clearly, insights from the field of IF might be beneficial in this context.

An additional challenge when considering an IF system as a DSS is that the system does not conform to the neat logical view of DSS. For instance, DSS do not usually accommodate the active user, an aspect which is typically taken into account in IF systems (in comparison to DSS). Similarly, Patel et al., (2002) recognised that there is a general need to go beyond the traditional view of DSS, that is, we need to look beyond the classical decision-making theories upon which it is built. Patel et al., (2002) acknowledged that rather than focusing on classical
decision-making theories, we need to focus on (1) problem solving skills, (2) capturing the nature of decisions as in line with Naturalistic Decision Making, and (3) the technology (i.e. decision support) needs to be considered as a mediator of performance. In other words, there is a need to change how DSS is approached, in order to build successful technology which can mediate human decision-making processes. These issues are also applicable to IF systems. Hence, there are known limitations of DSS which need to be considered before treating IF systems as DSS. However, by starting with a special class of fusion based DSS, and by utilising a DCog perspective (in the form of CASADEMA), as in the present thesis, the above identified challenges can be limited. It is interesting to note that the limitations of the DSS paradigm, as demonstrated by Patel et al., (2002), have yet to be noticed by the mainstream DSS community.

10.3 Increasing Methodological Needs in IF

The recent change of the user perspective in IF, from a passive receiver to an active contributor, creates a need for new methodologies, which is further reinforced by the drive in the IF community to increase the level of automation. The historical evolution of the role of users in IF has been revealed in the literature review presented in Chapter 3. It can be argued that the methods commonly used in IF (cf. Section 4.2) can capture the interaction with IF systems well, assuming that the user is merely a receiver of information. When the perspective is changed to the rather active user, new requirements emerge. The need to introduce new frameworks in IF is thus recognised, for instance, by Bisantz et al., (2004), Mahoney et al., (2008), Muller, (2006), and Muller & Narayanan (2009), who promote the use of cognitive engineering and work domain analysis.

In this thesis, we argue for using a DCog perspective in the form of CASADEMA to be able to capture this new role of the users. Indeed, Cox et al., (2007) recognise that a DCog analysis can provide valuable knowledge regarding systems which need to increase the automation. More specifically, this work thus extends the previous attempts that have tried to use DCog to gain novel insights into HCI, in general, e.g., Eden, (2007; 2008), Peter Wright et al., (2000), and socio-technical environments as well as decision support, in particular, e.g., Hazlehurst et al., (2008) and Patel et al., (2002).
10.4 Capturing Semi-Automated Decision-Making with CASADEMA

Theories developed within the framework of naturalistic decision making (e.g., the recognition primed decision making model (Klein et al., 1989; 1998), and the integrated naturalistic decision model (Greitzer, Podmore, Robinson & Ey, 2009) typically do not involve interaction with a computerised decision support tool. Rather, those processes have emerged when studying (expert) decision makers in a naturalistic setting. Hence, such theories may have limitations in explaining the interaction between humans and technological decision support as they do not typically account for the role of external artefacts to amplify cognition. For instance, Klein (1989, 1998) recognition-primed decision making model is heavily built upon the decision maker’s previous experience and knowledge. That is, the process depends on the decision maker’s ability to match a new decision situation with previous experiences. However, in Case Study 2 (cf. Chapter 8), a real-time decision making process emerged in which the operators appear to be engaged in is an active construction process in which information provided via technology is combined with their own knowledge, rather than a pattern-matching processes based on experience (mentally stored in the decision maker). This finding is similar to those of Vincente, Mumaw, and Roth (2004) which studied how operators monitored a nuclear power plant.

In addition, by being grounded in DCog, CASADEMA steps away from the traditional information processing paradigm, which typically illustrates a sequential model of sensation, perception, decision making, problem solving, planning, and action. In the case studies presented in this thesis, these activities are distributed and intertwined. For instance, monitoring would, with a traditional information processing paradigm, involves the activities of sensation, perception and attention (cf. Vincente, Mumaw, & Roth, 2004). In Case Study 2 (cf. Chapter 8) monitoring is described as a much more complex and active process involving, e.g., problem solving and progress tracking.

Moreover, one of the most typical methodological approaches for capturing human decision-making and thus creating general decision-making processes has been through interviews (cf. Section 4.3). As previously mentioned, there are some limitations when relying solely on interview techniques for the capture, since one depends on the decision maker’s ability to, in retrospect describe decision-making activities (i.e., it is difficult to verbalise behaviour). In this thesis, we have developed a method aimed at capturing semi-automated decision-making, in particular, in fusion contexts that emerge in the human interaction with technology (e.g., fusion processes). This method particularly focuses on observing the interaction (as defined herein) as a way of capturing emergent phenomena. This approach thus may have possibilities to overcome typical challenges associated with, e.g., interviews (as described above).
Traditionally, the result of a DCog analysis is a description of the artefacts used and the propagation of information within the system of interest (cf. Chapter 5). To the best of our current knowledge, DCog is not typically used to produce a decision-making process as described herein (cf. Section 7.4.3). However, we see in this thesis that using DCog to capture decision-making opens up interesting possibilities to capture a dynamic decision-making process with less emphasis on using an internal mental model for which to base the decision.

10.5 DCog from a Theoretical Framework to a Methodology

As a theory, DCog has by and large remained much unchanged since its introduction in 1995 in terms of the work of Hutchins (1995a), however, more recently the theory has been elaborated to encompass embodiment aspects (cf., e.g., Hutchins (2006)). In particular, there can be different reasons why DCog has not been formalised to a greater extent. Some argue that not having a formalisation (and thus the flexibility to choose the study focus and/or level of analysis) is the strength of the theory and there is no need to develop it further (Halverson, 2002). On the other hand, it has been argued that it is necessary to structure DCog to increase its applicability (Moore, 1998). In other words, DCog is a considerably young theory, and there are still open questions regarding how to best analyse and model cognitive systems in terms of DCog. This section thus revolves around the following questions: How does one go from a theoretical framework to a methodology, and what are the benefits and disadvantages of such a step? These were some of the major challenges for this thesis during the development of CASADEMA.

Let us further consider the difference between a framework and a method. The intention of a framework should be to function as a guideline, a loose structure which remains flexible in the sense that it does not restrict the addition of new findings within itself (Crick & Koch, 2003). The illustrative example highlighted by Crick & Koch (2003) is from molecular biology; the structure of DNA can be regarded as a framework. Although the framework turned out to be generally correct, it did not predict the existence of introns or RNA editing. A method, on the other hand, is more structured and often provides “how to” knowledge, for example, it can help to structure a process, organise activities and results, make progress, to plan a project (sub goals and deliveries, etc.), and so on. Thus, proceeding from a framework to a method requires a higher level of formality. This change could possibly result in restricting new ideas from being included in the underlying structure, since the objects and parameters of interest are more rigidly defined.

Transforming DCog from a framework into a method can thus make the approach less flexible. Some therefore argue that the lack of a formalisation (thus
retaining the flexibility to choose the focus of the study and/or levels of analysis) is actually the strength of the theory and there is no need to develop it further (Halverson, 2002). Some even assert that DCog cannot be turned into a methodology.

However, there are many reasons in favour of a more methodological (i.e., structured) format. One is that it would allow for a better linking of the data collection to the data analysis (and the possible design of future systems). As an example, McMaster et al., (2006) particularly point to the problem that ethnographic studies are not easily transform into a formal computational structure. A more formal approach can thus bridge the gap between data collection, analysis and design (cf. Wright et al., (2000)). Furthermore, aiming for a more methodological format can increase the generality of cognitive systems and increase the possibility of finding general properties of the broader cognitive system. Currently, there are many interpretations of DCog (cf. Chapter 5), and it basically depends on the individual researcher to use the concepts in whatever way suits them.

Another point is that it is easier to introduce the framework into new domains, if it is more structured. Moore & Rocklin (1998), for instance, argue that it is thus necessary to structure DCog in order for it to be successfully implemented in new domains. Interestingly, explicit definitions of concepts are usually found in papers introducing DCog into new domains (e.g., Hazlehurst et al., (2008) and Hazlehurst et al., (2007) introducing DCog into the health care domain). Similarly, in this thesis, in order to successfully introduce DCog into the IF domain and increase the acceptability of the ideas, we have had to define concepts and show in detail how our conclusions were reached (hence, the developed CASADEMA). We thus progressed a step further than Hazlehurst et al., (2008) and Hazlehurst et al., (2007) did when introducing DCog into the health care domain. The explicit need for a method like CASADEMA, when introducing DCog into IF, could be a consequence of the technological and mathematical orientation of the domain. We therefore believe that presenting the DCog ideas in the form of CASADEMA will make the theory more accessible to the domain.

The need for a more structured DCog approach is reflected in the many new methods developed in recent years to capture various human technology interactions (e.g., Wright, (2000); Eden (2007; 2008); Galliers et al, (2007); Nilsson et al, (2008); Rinkus et al, 2005). These methods are typically concerned with structuring DCog into a step-by-step process for the purpose of understanding the effects of artefact use within the system. It can be argued that a more formal approach is the requirement necessary to take DCog forward. Indeed, we believe that a more formalised DCog would be beneficial, and have, in this thesis, provided an initial step in this direction (i.e., CASADEMA). Overall,
the approach presented in this thesis is not intended to replace any other approaches in DCog. As such, it does not restrict the freedom and flexibility of DCog. However, if the chosen level of analysis allows the modelling of a system in terms of different states within it and relationships between those, then we have shown it is possible to proceed beyond a mere textual description of this system and extract novel and useful information. For instance, as illustrated in Chapters 7-8 it is possible not only to capture the fusion process, but also emergent decision-making ones. Thus, we confirm the theoretical benefits of a DCog approach for analysing decision-making systems (Hazlehurst et al, 2008; Patel et al, 2002).

10.6 Methodological Assessment of CASADEMA

A method can be regarded as many different things: an aid to structure the process; an aid to organise activities and results, an aid to make progress, an aid to plan a project (sub-goals and deliveries, etc.). It is important to keep in mind that a method is not just a simple “recipe” for success, it also has to be used with good judgement. Consequently, measuring the use and impact of a specific method takes years. Furthermore, it is difficult to determine a priori what constitutes a good method since this is often situation- and context-dependent. A method’s effectiveness is also heavily influenced by its ability to fulfil its promises in terms of purpose and goal. Finally, whether or not a method is considered to be “good” can also be highly influenced by personal preferences and experience (as well as one’s theoretical perspective).

In an ideal world, it would be possible to assess the quality of a method by using it in parallel with others on the same data, thus ensuring that the methodologies can be compared empirically and on equal terms. However, this would only test the method’s ability to capture the tested data but not its versatility. In this thesis, we have seen two versions of CASADEMA during the development of the method (cf. Chapter 7-8). Both use a similar structure (e.g., Case Study 1 was based on participants’ observations, while Case Study 2 was based on interviews and direct observations). The identification of the fusion process (and related cognitive aspects such as decision-making) in both case studies implies the effectiveness of the method. It could be asserted that the method is, to some extent, empirically validated. In the following, we further elaborate on the quality of CASADEMA as presented in this thesis.
10.6.1 CASADEMA as an Analytical Method

Considering the structure of CASADEMA, its major purpose is to *analyse* rather than to evaluate. Analytical methods in the area of Human Factors can be described as a category of methods that “help the analysts to gain an understanding of the mechanism underlying the interaction between humans and machines” (Stanton et al., 2005, p. 3). Analytical methods are often based, amongst others, on direct observations, performance records, and questionnaires (Annett, 2002).

It can be argued that CASADEMA, at its core guides the researcher in performing a DCog analysis. As Perry (2010) has pointed out “[a] distributed cognitive analysis examines the means by which the functional system is organised to perform problem-solving. From a computational perspective, the functional system takes in inputs (representations) and transforms these representations by propagating them around the units of the system. A distributed cognitive analysis involves deriving the external symbol system (cf. Newell and Simon, 1972) by capturing the elements of processing (representations and processes) that transform system inputs into outputs for particular tasks” (p. 389). As shown in detail in Chapter 9, CASADEMA fulfils the requirements set out by this statement, and thus encompasses the spirit of a DCog analysis.

Furthermore, as an analytical method, CASADEMA needs to fulfil a number of different criteria. Annett (2002), for instance, indicates that *construct validity* (as opposed to predictive validity) and *reliability* need to be considered. We must therefore examine how CASADEMA needs to take these criteria into account.

Firstly, *construct validity* is related to how “acceptable” the underlying theory is, although what exactly is considered acceptable can change over time. As an example, our knowledge of error management has increased over the last years and, consequently, proposing a methodology based on early error theories would not be particularly acceptable today (Annett, 2002). Hence, during the development of CASADEMA, it has been important to define and be explicit regarding the underlying theory on which the methodology is based (in this case DCog). Indeed, Dix (2010) argues that “empirical evaluation needs to be part of a theoretical argument or some other form of justification”. In this thesis, we have argued that DCog is an appropriate choice for capturing the interaction between the decision maker and technology in semi-automated fusion processes, due to its distributed nature and successful application in explaining human computer interaction in dynamic and complex environments (see Chapters 4 and 5 for further discussions on its applicability and Chapter 8 for information regarding how the theory influences the procedure of CASADEMA). In other words, the identified data can be interpreted in light of the model, to reveal the
components of the fusion process and the broader cognitive context in which it occurs. Thus, CASADEMA fulfils the construct validity criterion.

Furthermore, the reliability of analytical methodologies has always been questioned. In this thesis, reliability refers to the repeatability of the results, that is, the likelihood that different researchers would obtain the same results using the same methodology (Annett, 2002). Allowing other researchers to use CASADEMA would be an ideal way of testing the reliability. This has, however, not been possible due to time constraints. Nevertheless, if the reliability of the method were to be tested, it would not be trivial. As Annett (2002) argues, it has been shown that the quality of results depends on the training and experience of researchers. Thus, a difference between results may not depend on a problem with the method, per se, but rather, may depend on the user of the method. This issue has been considered during the development of CASADEMA, and it has been pointed out in Section 9.1 that the user of CASADEMA needs prior knowledge of Human Factors, or similar. Additionally, to further increase the repeatability of the methodology, CASADEMA has a defined procedure (including a notation and definitions) and a narrow focus. This increases the likelihood that different users of the methodology would, nonetheless, use it in a similar fashion and, consequently, that CASADEMA can fulfil the repeatability criterion to a reasonable degree.

10.6.2 CASADEMA as a Descriptive Method

In addition to analysing interaction in semi-automated fusion processes, CASADEMA also claims to describe the interaction. To evaluate whether or not CASADEMA can successfully do so, we can turn to Halverson, (2002) who defined four criteria for assessing the abilities of DCog and Activity Theory to inform the design of Computer Supported Collaborative Work applications.

Firstly, Halverson (2002) defines descriptive power as the ability to make sense of and describe our world. Halverson (2002) argue that a conceptual framework contributes to the descriptive power, that is, one should be able to define theoretical constructs as well as the relationships. If one has a conceptual framework, one can use it to describe and interpret what is being observed. Considering the development of CASADEMA, the definition of the unit of analysis contributes to the descriptive power. DCog provides a conceptual framework for CASADEMA which also contributes to the descriptive power.

Another important factor in being able to describe phenomena and inform a domain is rhetorical power, which refers to the ability to construct a conceptual structure that can be mapped to the real world. With such a structure, the communication of the work to other people can be facilitated (that is, there is an underlying ability to persuade others that the proposed view is the correct one).
DCog as a theory, traditionally has a rhetorical disadvantage over, e.g., Activity theory (Halverson, 2002). In particular, difficulties in the communication of its ontology are emphasised. CASADEMA, which is a DCog method, addresses this issue by complementing the theory of DCog through the introduction of a notation and a definition of concepts, as well as instructions for their use.

Interferential power (Halverson, 2002) is a related concept, referring to the ability to make inferences about phenomena which, for instance, we do not yet fully understand where and how to look for. Moreover, to claim interferential power one should also be able to suggest changes to design (i.e., make inference). This requirement is beyond the scope of CASADEMA, which is a method aimed to capture and understand phenomena that is not obvious at first sight since it focuses on interactions between elements (cf. DCog). CASADEMA does not provide design suggestions, which currently fall outside its intended use.

Similarly, application power (Halverson, 2002), which is the ability to transform the result into practical use in terms of system design, also goes beyond the scope of CASADEMA. However, it has been an ambition, with CASADEMA, to aim for an analysis and description of the world at a detailed level of analysis that has possibilities of aiding future system design.

Taken together, we can conclude that CASADEMA, although it is in its initial stage, encompasses abilities to describe interaction.

10.7 Reflective Summary

This chapter has presented a discussion on the implications of the development of CASADEMA and the output which can be produced from its use. Briefly, these are:

- A DCog perspective (realised in the format of CASADEMA) leads to an extension of what is typically included in the fusion process.
- Classifying IF systems as decision support systems changes the perspective of IF beyond merely the peripheral support of human decision-making.
- Changing the role of the user in IF leads to the need for new methods in IF.
- Changing DCog from a theoretical framework into a methodology enables the introduction of the perspective into IF.
- Capturing semi-automated decision-making with CASADEMA enables the visualisation of otherwise non-verbalised processes.
- Assessing CASADEMA leads to considerations of what constitutes a good method.
In line with Galliers et al., (2007), the CASADEMA method is motivated by the vision of Hollan et al., (2000), and can be regarded as a practical application of DCog. We believe that a more formalised DCog (e.g., in the form of CASADEMA) would indeed be beneficial when being introduced into new domains such as IF. It would not only be valuable for increasing the possibility of informing future design, but also for increasing the possibility of learning about the cognitive system itself. Thus, CASADEMA can be regarded as addressing some of the limitations identified by, for example, Cohen et al., (2006). At the same time, the approach presented here is not intended to completely replace any other DCog approaches such as Hutchins (1995). As such, it does not restrict the freedom and flexibility of DCog in general.

The ambition with CASADEMA has been to present a simple method, which can provide structured knowledge regarding the components of the fusion process as it includes both humans and artefacts. In the theoretical assessment, considerations regarding validity and reliability have been taken into account in the development of CASADEMA. It can also be concluded that CASADEMA has the ability to analyse and describe phenomena existing in real life. Furthermore, CASADEMA possesses some of the characteristics necessary to be able to inform, for instance, the IF community. It thus has both a theoretical grounding and the ability to explain the concepts used. Considering the applicability of the method, from the practical assessments, it can be suggested that CASADEMA works best for studying existing complex systems (with a fusion element) rather than prototypes (which may not yet have a defined context). However, there is a need for further validation and development since there are still room for improvements (cf. Section 11.3).
CHAPTER 11

Conclusions and Future Work

This chapter lists the main findings of this thesis and presents an outlook on future work.

11.1 Main Findings

In this thesis, we have seen that an apparently simple decision can be complex and require fusion of multiple information sources, sometimes under great time pressure and much information load. The drive for the research presented in this thesis has thus been to obtain a better understanding of such complex situations, and the interdependencies which emerge. It can be argued that the fusion processes presented in this thesis (cf. Case studies 1 and 2) are too simplistic (or too human oriented) to be appropriate representatives of advanced fusion processes in general (which might be more complex, much less interactive, or even fully automated and not involving human operators at all). Also, it can be argued that the models presented herein capture neither human cognition nor computational aspects of fusion in great detail. However, the point of this thesis is not its universality, but rather to illustrate that (1) in many real-world fusion cases many of the quite abstract models of fusion (e.g., the JDL model) have their limitations, that (2) the approaches used to study human-computer interaction in IF actually capture only some of the numerous relevant aspects, and that (3) a DCog perspective can help to overcome some of these limitations. In other words, the aim has foremost been to contribute to the IF domain, with an underlying perspective of having a user (i.e., decision maker) point of view and an emphasis on empirical research.

More specifically, in this thesis we have put forward theoretical arguments regarding the applicability of a DCog perspective on IF (cf. Section 5.5) which
have been further reinforced in two empirical case studies (cf. Chapter 7-8), and realised in the format of CASADEMA (cf. Chapter 9). This has resulted in the following findings:

- Identification of fusion processes which go beyond the processing of a specific technical system alone, and recognising that the fusion process emerges from the interaction between technology and its user(s), and extends beyond user(s) and artefact(s), as illustrated in Case studies 1 and 2 (cf. Chapters 7-8). The fusion process, is thus shaped by that very interaction.

- Identification of components of semi-automated fusion processes in which (1) the user is characterised as an active component, and (2) the information sources are (roughly) considered to be automatic or requested, (3) non typical information sources (e.g., a radio in the background) are considered a prominent part of the process, and (4) interdependencies between the fusion process and cognitive processes (e.g., decision-making) are naturally included (cf. Chapters 7-8).

- Development of a methodology, CASADEMA that is theoretically and empirically grounded, and which includes a notation, definitions/description of concepts, as well as an outline of procedure. This method has (partially) been proven successful in two ways. Firstly, it has been shown to capture interactions in two different types of semi-automated fusion processes. Case Study 1 illustrates a technology oriented, low intensive (i.e., long time frame) fusion process, and Case Study 2 illustrates a human oriented, high intensive (i.e., short time frames, high pressure) fusion process. Secondly, it enables visualisation of otherwise internal cognitive processes (e.g., decision-making processes) (cf. Chapter 9).

- A DCog analysis (in the form of CASADEMA) which enables a linkage between data collection and data analysis by defining interaction as propagation and transformation of representational states between elements within the cognitive system. As illustrated in this thesis, a representational state refers to how knowledge and information are represented in specific elements (humans or artefacts) of the cognitive system. Information propagation thus relates to the functional relationships between elements. Hence, the focus in the analysis is on the communication between the elements within the system rather than the elements themselves (cf. Chapter 9).

- Definition and highlighting of IF systems as decision support systems which include (1) classification of IF systems as decision support systems,
and (2) characterisation of the decision environment which enhances a user perspective in IF (cf. Chapter 3).

- Deeper insights into the role of HCI and users in IF though empirical studies (cf. Chapters 6-8).
- Identification of a decision-making process emerging for the use of decision support, enabled through the application of CASADEMA (cf. Chapter 7). In particular, this is an real-time decision making process in which the operators appear to be engaged in is an active construction process in which input information is combined with their own knowledge (not to be misinterpreted as an pattern-matching process (cf. Klein, 1998)).

The above findings thus have implications mainly for the IF community, but also implicitly for the cognitive science and HCI discipline (cf. Section 1.6).

### 11.2 Addressing Open Research Challenges

The work submitted in this thesis has been motivated by the research challenges presented in Chapter 1. In this section, we briefly review those challenges in order to assess the work performed and the contributions of the thesis. Each of the challenges, together with its supportive work, is presented separately as follows:

1. Perform research investigating the active role of users and the cognitive interdependencies existing in fusion processes and contribute towards overcoming the technological focus within the field of IF

The above research challenge has been addressed by both theoretical and empirical investigations of the users’ role in IF (cf. Chapters 3 and 8). A number of empirical user studies investigating various user issues have been conducted (cf. Chapters 6-8), of which some have been enabled through the use of CASADEMA (cf. Chapter 9).

2. Investigate how IF systems actually support human decision-making in practice and thereby contribute towards overcoming the current trend to see IF technology as only peripheral to supporting decision-making

Research challenge number 2 has been addressed by theoretically classifying IF technology as decision support (cf. Chapter 3) and presenting empirical studies focusing on the ability of IF technologies to support human decision-making (cf. Chapters 6-8). Furthermore, through the use of CASADEMA, the
interdependencies between human decision-making and IF technology have been identified (cf. Chapter 7).

3 Investigate the possibility to adapt DCog to suit the field of IF and in particular structure the DCog approach into a method specifically adapted to capture interactions in IF contexts and thereby contribute towards overcoming the limitations associated with the methods currently used within IF to investigate interaction between humans and technology.

The fact that DCog has been structured in terms of CASADEMAd, to be used within the IF community, highlights the contribution to research challenge number 3 (cf. Chapters 5 and 9). In addition, it can be argued that the development of CASADEMAd has overcome the limitations associated with the traditional methods, highlighted in the above research challenge.

11.3 Critical Assessment and Future Work

The line of research presented here revolve around one important issue; bridging the gap between data collection and system design, that is, how one transforms an understanding of the usage of an existing system to design proposals to be implemented in the development of new systems. This research direction is particularly interesting since there is an implicit drive within IF towards an increase in the automation of the higher levels of the JDL model. In its present state, CASADEMAd is structured to provide researchers with an understanding of a current situation, with less focus on explicit guidance for design questions. In the following sections, we present ideas regarding how CASADEMAd can provide the foundation to answer such design questions.

11.3.1 Further Validation of CASADEMAd

CASADEMAd could benefit from further development and improvements. For instance, there is room for improvements concerning the notation. It might be more informative if the transformations (denoted with an arrow) would provide more information regarded what is transformed, e.g., physical to digital, virtual (i.e., work procedures) to mental structures, etc. To investigate the level of details of the notation in order to be most effective would provide interesting research challenges.

Obviously, so far, CASADEMAd has been applied in a limited number of case studies. It would therefore be interesting to further validate and improve CASADEMAd, testing its abilities in additional case studies. It can also be argued
that our case studies were especially well suited to a DCog-inspired analysis, since they involved a large number of interactions between the different components, humans and artefacts, of the system. There is thus still an open question regarding how successful a DCog approach would be in modelling a decision-making process that does not rely on a heavy use of interaction. Furthermore, CASADEMA has been used to capture events in highly structured environments (cf. Chapters 7-8). Encouraging research shows that a DCog analysis can be valid in loosely coupled systems as well (Perry, 2009). It would thus be interesting to see how CASADEMA can be adapted to work in such similar, loosely coupled systems.

Moreover, CASADEMA has been developed to function with existing systems. It would be interesting to investigate how CASADEMA can be used in the concept generation phase of a system development process where there is no existing system (e.g., in a similar style as Ferruzca et al., (2007) who used DCog to evaluate the design of learning systems). In such a situation the focus should not be on how the users perform a task, instead the focus should be on what they try to achieve. For example, a plane is always required to fly.

11.3.2 Using CASADEMA to Inform Design

Increasing the automation of a manual process is not straightforward; in addition to fusing the data captured in the physical and digital artefacts (e.g., information from a fax or database, a piece of paper with a list of attributes, radar readings, etc.), the artefacts themselves serve as cognitive support (e.g., external memory). This needs to be accounted for, in other words, the cognitive properties of the artefact must also be fused which is an aspect not typically captured by current methods. However, proceeding from the description of a process to design recommendations it is not easy.

Indeed, Perry (2003) argues that the limited success of DCog in the development of practical applications and recommendations for system designers is mostly due to the narrative style of the descriptions produced. It is argued that such qualitative and subjective data is not useful to system engineers. This is reinforced by McMaster et al., (2006) who argue: “there is a place for an approach that combines the underlying conceptual framework of distributed cognition with the more formal notations of system engineering”. Actually, Walker et al., (2010) used social network analysis and can thereby calculate the centrality of individual agents. Due to CASADEMA’s focus on the interactions (in terms of propagation of representational states) between humans and artefacts, more quantitative analyses are made possible, in turn, would provide the possibility to address this limitation. This focus would especially enable the
results of ethnographic studies to be transformed into formal computational structures.

An illustration of how a researcher with a quantitative background can perform such analyses to extend Case study 2 (cf. Chapter 7) is presented in the following. In particular, it is shown how a Markov-inspired analysis can be used to answer design questions (cf. Nilsson and Thill, internal document for details of how such an approach can be developed).

First, by focusing on how the different design features of the technology are used, and how they are manipulated in the conduct of activity (e.g., the use of directional arrow, electronic flight strips, digital communication for directing airplanes etc., in Case Study 2), one can capture the transformations of representational states. This data can then be classified into specific emergent properties (i.e., the decision-making activities identified in Case Study 2), see Figure 11.1. Further, by considering the propagation of representational states (i.e., in what order different design features are manipulated), the relationships between the decision activities defined become evident. The overall process thus identified can be visualised as a graph detailing the different states that operators and technology cooperatively can find themselves in (cf. Figure 11.1). Moreover, by calculating how many times a specific support feature is used, one could calculate the probability of the occurrence of a decision activity. For example, the operator initiates the process and start to explore the possible decision strategies (initiation-exploration). The operators then have a set of activities which can be performed (anticipation (0,2), grounding (0,2), selection (0,3), adaptation (0,3)).

![Decision-making process including transition probabilities. The arrows from each activity sums up to 1. The probabilities of going to the next activity are based on the usage of the associated technology features (which can be captured by observing the operator).](image)
More specifically, a Markov-inspired approach can provide additional information which would not emerge within the analysis provided in CASADEMA. One can, for instance, identify the most and least visited states in an average decision-making process. Also, if the average time an operator spends in every state is known, it would be possible to calculate how much time the process actually takes. It can also be possible to compute the likelihood of that state being visited during one run through the decision-making process. An additional benefit can be that it can equally apply to hypothetical models. If one were, for example, to make modifications to the system, it would be possible to calculate the likely effects of those changes to the system, if one can estimate the likely change in probabilities that the modification would entail. This can, for instance, be a consequence of improved design features of the decision support. That is, one can use this information to decide whether or not the gain is sufficient to justify investing in the modification of the system. One can also use the model to determine how failure of a component affects the system. For instance, one can analyse the consequence of an operator losing the ability to directly adjust a decision based on feedback, by removing the “Adjusting” state and linking “Feedback” directly to exploration. However, it should be kept in mind that this type of analysis obviously cannot inform on the quality of a decision but merely on the time it took to reach it.
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