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# A Cognitive Work Analysis as Basis for Development of a Compact C2 system to Support Air Surveillance Work

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## Abstract

### **A Cognitive Work Analysis as Basis for Development of a Compact C2 system**

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This Master of Science thesis is produced at SAAB Security and Defence Solutions. The purpose of the thesis is to analyze how air surveillance work can be carried out. This information is then used to give suggestions for the design of a new system containing only the most essential functionality. This is done by examining the available frameworks which can inform interface design and applying a framework to analyze work in a complete system used as the basis of the new Compact C2 system. The second part of the analysis is directed towards the stripped system (Compact C2) and both parts of the analysis are used to inform interface design of the Compact C2 system. By using the full range of the chosen framework for analysis of the identification process in Swedish air surveillance work, some essential functions were identified and should also have support in a Compact C2 system.

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## **Sammanfattning**

Examensarbetet som är det avslutande momentet på civilingenjörsutbildningen System i Teknik och Samhälle utfördes hos Saab Security and Defence Solutions. Den huvudsakliga uppgiften var att analysera hur luftbevakningsarbete kan utföras och analysen skulle sedan användas till grund för hur ett nytt system kan utformas.

Rapporten har tre delar; först identifieras ett ramverk som kan användas som grund för en analys. I steg två används ramverket för att analysera luftbevakningsarbete i Sverige och i steg tre tas förslag fram med analysen som grund.

För att ta fram ett ramverk för analys har litteratur inom kognitiv arbetsanalys (CWA) använts och för att analysera luftbevakningsarbete har fältstudier, intervjuer och scenariobaserade test använts. Förslagen har utgått från analysen och identifierat några nyckelfunktioner som måste uppmärksammas vid utvecklingen av ett nytt system. Rapporten föreslår vidare några viktiga områden för vidare analyser då luftbevakningsarbete är ett område som kräver mycket mer arbete innan en analys kan bli heltäckande.

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# 1 Introduction

*In this first chapter the scope and purpose is presented together with the research questions*

Technological advances have changed the type and amount of information available for making decisions on the battlefield. Compiling the best foundation for decision making has become imperative when managing forces on a battlefield.

Technological advances are not the only factors that have changed when controlling forces. Joint warfare and the collaboration between countries put high demands on the interoperability between systems in different countries. Adapting to these changes is imperative for countries belonging to military alliances or when practicing in exercises with multiple nations. According to Codner (2003) interoperability between countries' military is a very broad subject; interoperability can be used to describe the technical systems ability to work together, organizational factors, logistical interoperability and behavioural aspects.

Countries who are members of NATO sometimes do not have the full NATO compatibility, but still train with NATO forces. For these countries to effectively train their forces in joint warfare with compatible equipment they could use a lightweight system for accessing the compiled air situation picture, surveillance of their airspace, or leading their own forces.

Saab has designed many full-fledged command systems adapted to their customer's needs and with international compatibility; these systems are complex, big and expensive. Analyzing their market they see a market opportunity for a small, more generic version of a command system with the most essential functionality. The intended system is still early in its development process and does not have any users, customers or hardware. The new system being developed draws upon functionality and appearance of a system previously developed by Saab. The original (and larger) system at Saab has been iteratively developed with new functions added at a continuous rate. The interface design and structure is a result of the new functions that have been added, not as a result of the work functions and processes of the system.

When the new system is being developed with the previous system as base, there is a need to analyze the previous system in detail to develop suggestions of how the new interface design could be adapted to increased support of the operator's cognitive abilities and work. The previous system's functions should be identified and transferred to the new system with a design where operator interaction is well supported and adapted to the work tasks. This fact leads us to the scope and purpose of this thesis.

## 1.1 Scope and purpose

The purpose of this thesis is to analyze a full-fledged system for air surveillance to inform design of a Compact C2 system, where the design is well adapted to the work being conducted.

The aim of this study is, on the basis of an analysis and theories of interface design, to produce input to an interface design that is well suited for the operating conditions and also supports

cognitive functions, increases health and productivity, and promotes safety in a Compact C2 system.

## **1.2 Research questions**

What type of analytical framework supports a system analysis and gives information to interface design?

What is the working environment for an air surveillance operator during work in the full-fledged C2 (command and control) system?

What are the differences in the air surveillance work in the full C2 system and the Compact C2 system?

How can the Compact C2 system be designed to support the air surveillance work?

## **1.3 Delimitations**

Saab develops several different C2 systems (for both air and naval command and control). For this thesis focus is directed at the system with the most functionality, the C2STRIC system used by the Swedish defence and base for the new system. The complete C2 system supports air combat coordination, civil defence and air surveillance. To reduce the complexity and fit into a limited time frame, this thesis will only consider the work within the air surveillance division. The delimitation from the complete C2 systems analysis means that this thesis will not give input for the design of the weapon control or situation awareness aspects of a C2 system.

The purpose of the report is to inform the design of a new Compact C2 system and no programming has been used to achieve the purpose.

## **1.4 Readers Guide**

This thesis consists of several chapters encompassing purpose, theory, method, system analysis, a discussion with design development and conclusions. In chapter 1 (Introduction) the thesis' scope and aim is presented, this chapter gives the guidelines and the research questions that can be used as support for understanding what has been studied. In chapter 2 (Background) the background of the complete C2 system and air surveillance work is presented in coarse detail to inform the reader of the basics in air surveillance work with the C2STRIC system as a tool. In chapter 3 (Theory-previous work), a review of methods for system analysis is made and a framework for analysing air surveillance work is presented. This framework partly answers the first research question, additional aspects that were noticed during the analysis are presented in the beginning of chapter 7 (Discussion). Chapter 4 (Method) describes in more detail how the framework was used for analysing the system. This detailed explanation includes the kinds of methods that can be used to gather information and what reliability and validity the information holds. Chapter 5 (Air surveillance work and the C2STRIC-System) describes how air surveillance work can be carried out in a complete C2 system and thus answers the second research question, this information is structured and presented using the chosen framework for analysis. Chapter 6 (The Compact C2) is an analysis of the Compact C2 system, again this information is structured using the chosen framework for analysis and some changes for the system are presented at the end of the chapter. Chapter 7 (Discussion), discusses what experiences were gained from using the CWA framework for analysing the system and discusses design implications for the Compact C2 system. Chapter 8



(Conclusions) focuses on the results of this thesis and collects all the finding. Finally, chapter 9 (Reflections) is used to share experiences gained from the study and comments on the results.

## **1.5 Glossary**

The area of air surveillance is unfamiliar to many readers and the words used to describe the area are also new to most readers. Some of the abbreviations and words used throughout the thesis are explained in the glossary located in Appendix I: Glossary.

## 2 Background

*This chapter provides the reader with basic information about air surveillance work in and around the C2STRIC system, this information is important for the reader to gain a basic understanding of the system. After the C2STRIC introduction, the current problem with the C2STRIC system is presented*

### 2.1 Basic definitions

The system analyzed in this thesis is referred to as a complex sociotechnical system, and it is important to define what is referred to with this categorization. The definition of a complex system is not a binary value (it is either complex or it is not), there is a sliding scale describing the complexity of a system. The five dimensions described by Woods (1991) are used to determine to what extent the system is complex in this thesis; first comes the **dynamics** of the system and the dimension uses two variables for measuring; the extent to which the nature of a problem can change over time and the second variable describes the extent to which the system can change its state despite the user's interaction. The air surveillance operators (ASOs) work is very dynamic due to new aircrafts arriving and departing all the time. The second dimension is the number of **parts and their relations** to each other. A system is more complicated if there exists many parts and they are interconnected in a manner where a problem can be caused by multiple parts and every part can cause multiple problems. This dimension is also very complicated for work within C2STRIC system with many sources of information and many interconnected systems in place to deliver information. The third dimension is based on **uncertainty**, the extent to which a worker can rely on the data in the system, the data must be complete and the data should be able to correctly predict future states of the system. The information being presented to an ASO is very reliable, although not all information is present at all times and the level of uncertainty must be kept to a minimum, this means that the limited uncertainty that exist in the system still is too high. The fourth level is **risk**; the extent of consequences of a worker's decision. Risk for an ASO is quite high, the Recognized Air Picture (RAP) is used as basis for engagement decisions and a mistake has the potential to create big consequences. The final fifth level is **social**; if a system consists of numerous operators they have to interact efficiently with one another the system becomes more complex. The ASOs have to interact between themselves, their ASO leader, civilian operators outside and many other roles that also are needed for the system to function.

The air surveillance system produces a recognized air picture that is used to gain situation awareness. The reason the C2STRIC system exists is to present a recognised air picture which commanders can use to achieve dominant situation awareness and leading forces. A dominant awareness is thought to allow one side to utilize its resources to a higher degree and thereby affecting the completion of a mission (Alberts et al., 1999). The air surveillance battalion in Sweden uses the C2STRIC system to improve the situation awareness; this means that a clear definition of the word situation awareness (SA) is needed. The definition of SA is not self evident, there are several different ways to define the concept (Beringer & Hancock, 1989). In this thesis Endsley's (1995) definition will be used because of its generic properties. Endsley's (1995) definition is:

“Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (p.36).

As mentioned earlier, there are however other definitions (e.g. Smith & Hancock, 1995; Sarter & Woods, 1991; Carol, 1992). The definitions basically restate the meaning of Endsley’s definition, although they have been customized to specific domains. In the scope of this study Endsley’s broad definition is well suited to the thesis’s scope due to its simplicity and ability to encompass the operators’ knowledge and understanding of the environment.

There are several different ways to define a command and control (C2) system. The definitions however are often adapted to specific systems. One definition according to Coakley (1991) and broadly used, describes Command and control (C2) as what a commander uses when making decisions and monitoring the execution of orders to accomplish the assigned mission. The C2 thus involves people, information, procedures, equipment and the commander’s own mind when; planning, controlling, coordinating and directing own forces (Stanton et al., 2008). This generic definition is used in the study to define the characteristics of the system.

The C2STRIC goes under several different names and one of the commercial names of the full-fledged customized remake of the C2STRIC system is 9airTOCCS C4i system. The definition of C4i (command, control, communications, computers and intelligence) has generic properties well suited to the system being studied. The properties are; (1) the system works goal-oriented and a C4i system has a common goal (or sub-goals). (2) The work done within the C4i system can be individual or team-based, although there is a need to coordinate the work. (3) The people working together within the system does not have to be collocated, they can be stationed at completely different locations. (Stanton et al., 2008)

To summarize; the C2STRIC system can be categorized as a complex sociotechnical system where its C4i properties place a high demand on design to achieve the best SA through the external model of the RAP (external model refers to the model put together with sensors and maps representing the real world).

## **2.2 The origin of the C2STRIC system**

For Sweden to maintain their territorial integrity they need to protect and guard their borders, by both surveillance and refusal of entry. The system used for maintaining Swedish territorial integrity of air space has been evolving since the first system was implemented 1923. The surveillance started with optical observations and telephones to compile a recognized air picture (see Figure 1). In 1944 Sweden got its first radar stations which improved accuracy and better information to the recognized air picture. At the end of 1950 Sweden got modernized with more and newer radar stations all connected to air defence centres through telephone and these centres divided Sweden into several air sectors. During this era the Soviets shot down two Swedish aircrafts (a DC3 and a sea rescue aircraft). This led to the conclusions that Sweden required a better air surveillance and incident preparedness to protect the national territory and operations. The requirements were met by further advances in technology and the information became computerized and sent to the air defence centre where it was displayed electronically to a local operator and the new technology allowed for around the clock surveillance. The electronic system was further developed in 1990 and its central node became the C2STRIC (combat management

central) system, a software system used for compiling all radar information from Swedish radar stations and displaying it to operators on a single screen. (Törnell, 2003)



Figure 1; The STRIL central before computerizing the information (Törnell, 2003, p. 45)

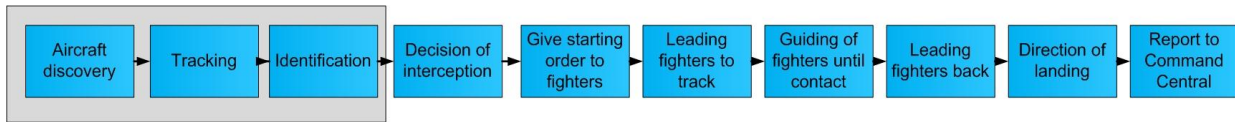
## 2.3 Fighter Coordination and Air Surveillance battalion

The customer using the C2STRIC system is a part of Swedish armed forces and is called STRIL. The STRIL battalion is concerned with air combat management and air surveillance. Its main task is to maintain Swedish territorial integrity by radar surveillance and combat management of military aircraft divisions. Air space surveillance compiles a recognized air situation picture which is used for intelligence, alerting the search and rescue, protecting the borders and direct military aircrafts. The air surveillance operators compile an identified and comprehensive air picture (RAP) and the combat aircraft leaders on the other hand convey the RAP to fighter, update mission tasks and coordinate fighters for an effective operation.

### 2.3.1 The C2STRIC system and air surveillance

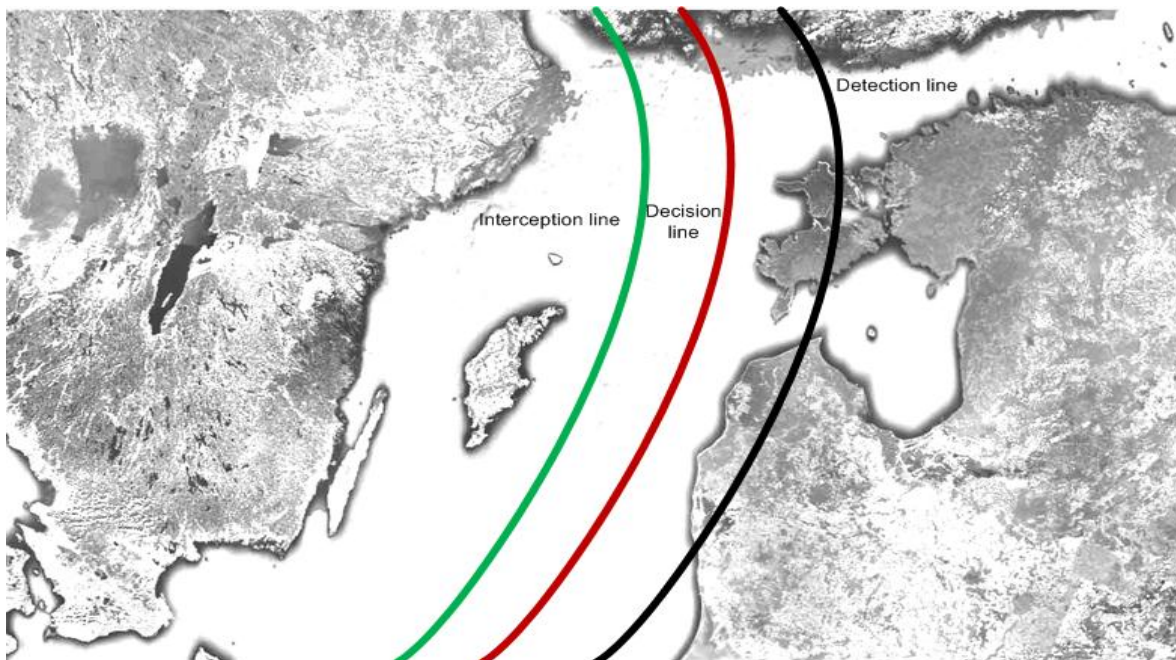
The C2STRIC system includes software, computers, communication means, interaction tools and displays. This system is used as a tool for the purpose of defending Swedish national territory and its functions are; to provide a RAP, **allow for military aircrafts to be coordinated** (battle management), **resource management** (manage resources available in air bases), **airspace management** (directing civilian aircrafts moving within areas controlled by the military), **air raid warning** (warn the civilian population of incoming attack) and finally **air traffic control** (if something happens to the civilian air traffic control the C2STRIC system can be used as a backup). All these system functions have several abilities and have many smaller tools to support them. The system allows for a complete overview of where all aircraft are located in and just outside Swedish airspace. This thesis will not go any further to describe all these functions within the system; instead it will purely focus on the air surveillance division.

When an aircraft is discovered by radar stations and the plane is approaching Sweden, it starts a chain of events. In Figure 2 the chain is illustrated; a plot is seen by a radar station and is tracked by a computer and becomes a track. The track is identified and if this track is then considered to be a threat, the rest of the chain follows. In this thesis however the focus is on the first three steps as indicated by the grey square in Figure 2.



**Figure 2 the chain from plot to engagement (Interview person 3)**

Following from the chain in Figure 2, it is easy to see that it is important for early discovery of threats and a fast and reliable identification of an aircraft for supporting the decision of engagement before the track can threaten the nation's sovereignty. An illustration of this fact can be seen in Figure 3, where it is important that the first (black) line is as far away as possible to allow for a long time to make a decision of intercepting an approaching threat.



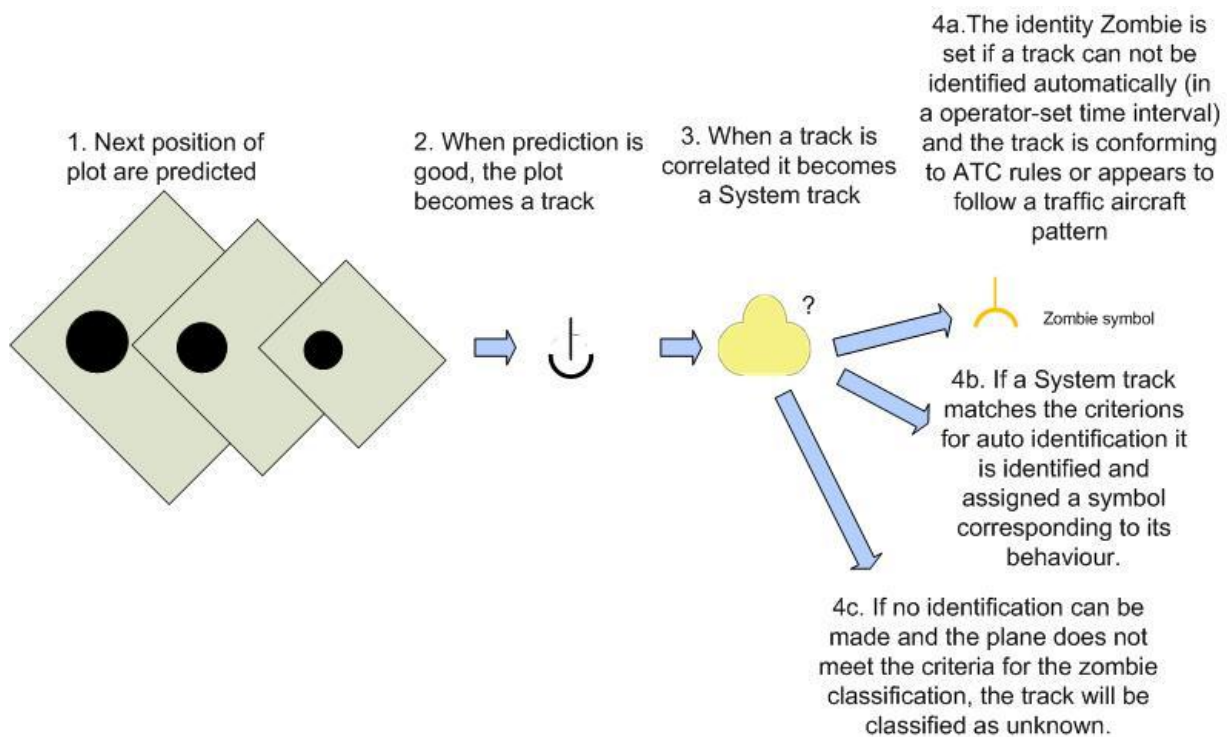
**Figure 3 the three lines illustrating different stages of the engagement chain**

## 2.4 Using radar stations to show aircraft on a map

For a greater understanding of how the radar information was computerized, the word 'track' should first be explained. When a radar sends signals, they bounce off surfaces and reflect back to the receiver, using a monitor, these reflections (known as plots) are shown. If the system or worker can see a pattern among displayed plots, indicating a moving object, this object can be added as a 'track'. The first step in Figure 4 describes the systems automation of finding a pattern among plots, the squares represents a simplified explanation of how a prediction and correlation occurs. The plot boxes used for prediction of next plot can be adjusted in size for not taking up too slow moving objects (like tanks and boats) and adjusted to not taking up too fast moving objects which can be a false echo due to weather. The process of spotting a pattern between plots can be done by



operators who can also add a track manually. Step 2 (in Figure 4) shows the symbol of the track (all symbols in the C2STRIC system follow NATO directions for appearance) and the line going out of the symbols indicates direction and speed of the track, if a track travels fast the line will be long and pointing in the heading of the track. When the track has enough data to safely say that the track is an aircraft, the track moves to step 3 and becomes a company (the word company refers to a system track, i.e. track that the system determines to be referring to an aircraft) ready for identification. In step 4 the company is subjected to the identification process and an identity is set. There are also different kinds of companies, local companies and remote companies. Local companies are the tracks being spotted within the current central and remote companies are tracks not identified by operators in the local C2STRIC Company (e.g. tracks from surveillance plane or another C2STRIC central). All tracked companies in the system are assigned a track number; this number is used by the system for referring to the unique aircraft and can also be used by operators when communicating about a specific aircraft and the label also contains information of which participant in the network of surveillance nodes that first spotted the company.

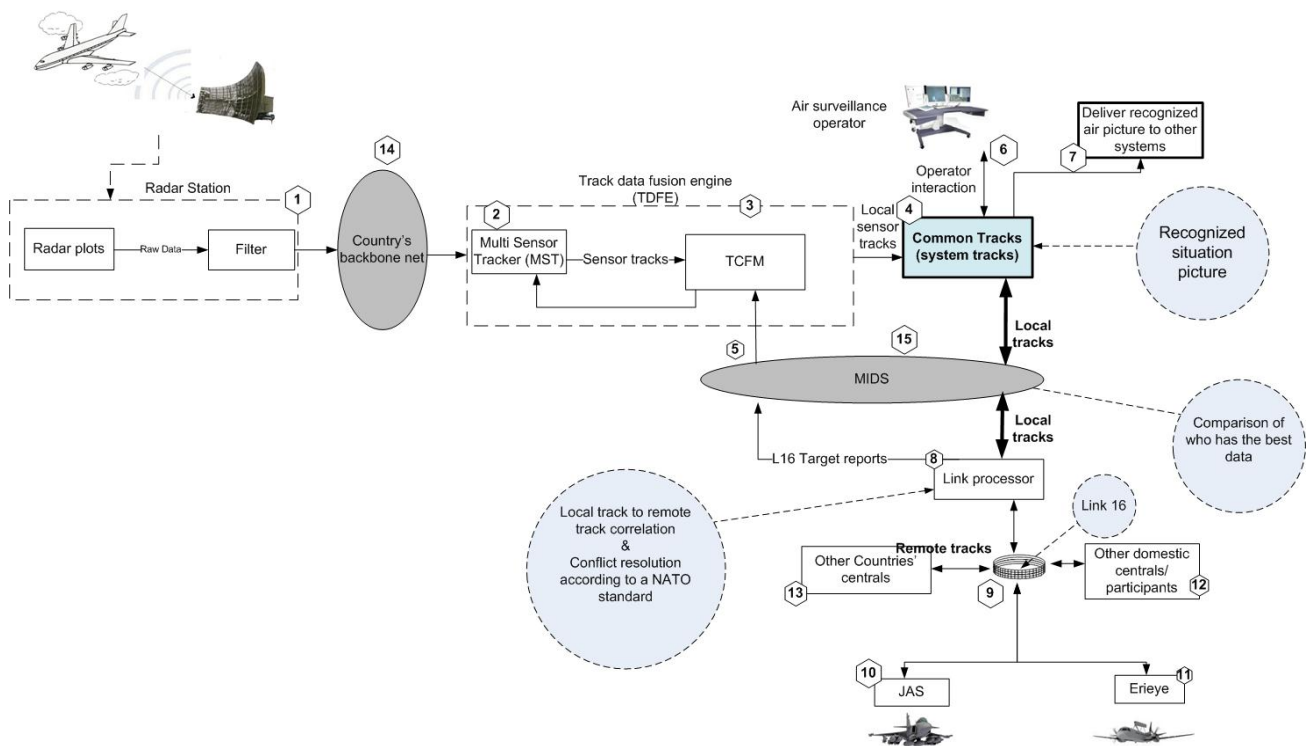


**Figure 4 Plots are converted into a track with a certain degree of probability**

The whole idea of identification is to classify aircraft in the airspace by assigning symbols corresponding to what is known about a track in the system. The classification with symbols is made to help commanders to gain a correct and rapid understanding of the recognized air picture and achieve dominant situation awareness.

A more detailed illustration of how the C2STRIC system receives its information, what kind, from whom and why, can be seen in Figure 5. The chain starts in the upper left corner (1) when a radar station sends signals and they bounce back into the receiver. The station receives radar plots of where the echo comes from and then filters the raw data to convert the signals to a common

coordinate system and process the data to minimize systematic errors. The next step in the process is that the tracks enter a data processing computer (TDFE, 3), this computer consists of a multi sensor tracker (MST correlates plots from several different radar stations) and the Track Correlation and Fusion Module (TCFM, comparing information from sensors with information from other sources and correlates the information). In short the TDFE evaluates if plots are the reflections of an aircraft (corresponding of step 1 in Figure 4 above) and if the target already has been spotted by other sources (coming in from (5)) it makes sure that only one track is shown on the screens for each aircraft. If the track is new, the track becomes a local track and is transported to (4) the common tracks; this is also the recognized situation picture. Among other things (e.g. filter and local tracks) it is this common situation picture the operator interacts with and compiles (6). The recognized situation picture is also transmitted to several other locations (7) and one of many recipients of the information is a network called LULIS (recognized air situation information system), this system is used to display the recognized air situation picture to battle centrals, the network is only for delivering the RAP and does not allow for recipients to change or add information. The information in the common tracks (4) is compared to the information from remote centrals (8). The information being sent to the comparison is defined as local system track (this track is followed by sensors connected through the country's backbone). The remote sources are connected to the comparison process by a tactical network called link 16 (9). The sources can be an air surveillance plane (11), Griffin (JAS 39 Gripen, or simply JAS) (10), other domestic surveillance centres (12), other countries' centrals (13), etc. The tracks coming from all these external participants are named remote tracks (this definition is based on the fact that only external sensors can follow the track) and are transported through the link processor (8) where a comparison of who has the best data and which identity should be used to identify the aircraft. The evaluation of the information is done by consulting a NATO standard for conflict resolution. The link between the C2 system and radar information is handled by a "backbone net" (14) where information is transported from the radar stations spread out in the country. The other link (15) is the infrastructure connecting the C2 system to the link 16 network.



**Figure 5 Schematic picture of how sensor-track information is processed and explanation of local-, system- and external tracks (own design).**

A short summary; the main task for the air surveillance work is delivering the RAP where all aircraft have been properly spotted, identified and to find deviations from what is normal behaviour of an aircraft. This is done by radar information from across the country being collected and presented in the C2 system. This information is then processed and presented to operators who use it to spot, identify and track all airborne vehicles. The aircrafts spotted by the radar are presented on the map within C2STRIC with the method described in Figure 4. The resulting RAP is then presented to commanding officers who decides what actions need to be taken to minimize threats and to the fighter leaders, directing friendly forces with the information.

In peacetime there is one facility at once caring for the functions of surveillance, coordination of civilian and military aircrafts, and leading military aircrafts. However lately redundancy in Sweden has increased and sometimes there are two stations operational and the responsibilities are shared.

In peacetime there are special rules for protecting the borders. Sweden avoids shooting down trespassing aircraft and most incidents concerning Swedish and foreign aircrafts are reported to an intelligence division where the information is processed. If the information of a violation of air sovereignty potentially can result in a complaint to or from a foreign state, it is sent to the foreign ministry and appropriate actions are taken. The other way of handling trespassers is to send two fighters to escort a trespasser out of Swedish airspace.

In the old systems of air surveillance the workers all sat with flickering green screens and dimly lit bunkers trying to see patterns in plots, this is a long way from the brightly lit offices and high performance machines cognitively designed with big ergonomic colour-filled screens used in current air surveillance work (see Figure 6). When a worker comes to the console, an assigned role

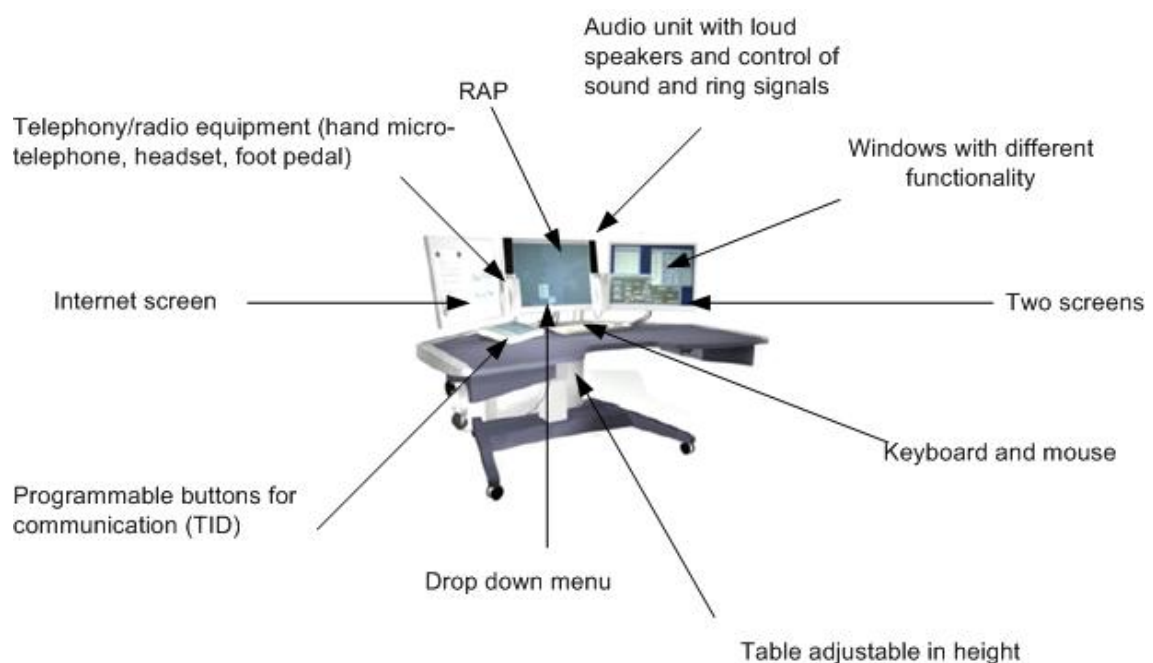


is chosen and the system adapts available functions for the role. After this, the system allows for the operator to load their predefined settings and windows. And work is usually carried out in groups of three operators and one air surveillance leader seated close to each other (as can be seen in Figure 6).



**Figure 6 Working conditions in a C2STRIC central (picture from SAAB presentations, used with permission)**

The C2STRIC is placed in the office environment seen above and the console used as a tool for air surveillance is shown in Figure 7. This system is also used as the basis for developing the Compact C2 tool that will be used in a Saab customer's air surveillance division.



**Figure 7 an operator console for air surveillance work (Picture from Saab presentations, used with permission)**

## 2.5 Developing the C2 system

The development of the C2STRIC system has been done iteratively and the customer (Swedish military) has the final word of how the system should look and work. This means it is designed with the user in focus over a period of several years, where new functionality has been added in the form of new windows and widgets that can be placed on the desktop. This type of development has led to a very advanced system with a lot of hidden functionality. The new

functionality in the system has been developed with focus on the functions. This has led to the interface design to be a result of the systems functions and lacking context sensitivity to the tasks that the operators perform.

When developing a new system with the basic functionality there is a desire to change the layout of the system. The system should be designed to fit with the cognitive processes of the operators using the new functionality of the system and the tasks currently being performed. The system should be designed to give support to the operator handling unanticipated situations which means that the operator's understanding of the system is an important factor to consider and design for.

To find out the important aspects affecting the operator, a structured method for analysis is used. In the following chapter, a method for analysis is presented.

## 3 Theory- previous work

*There are several different paradigms and methods developed for analysis of complex systems (as defined in section 2.1). In this chapter the range and scope of different methods and paradigms is briefly explained, and finally thoroughly description of the chosen paradigm and method used to conduct the study is provided.*

### 3.1 Analyzing Command & Control Systems

There can be many different reasons for analyzing a C2 system; one is to describe the system, many of the systems currently used today are not properly documented and this documentation is needed for maintenance, evaluation, improvements, etc. Another reason to analyze a system is to formulate the assignments and requirements of the system, using an analysis in the development process make it easier to follow the guiding principles and develop alternative solutions. The analysis can also be used to choose what values should be used to measure compliance with the goal (e.g. safety, health, speed) and verify the proposed system with a customer before the actual system is developed. The third reason for the system is to support design, the analysis can be used to find good flow, adapt the layout for support of work and identify essential information. The fourth reason for analysing a system is to support system integration and control; this means evaluating new tasks and components implemented in the system, the analyse can also help designing test sequences testing the whole system in a correct way. The fifth reason for analysing a system is to support training of operators by specifying what knowledge they need, how simulations should be designed and how to evaluate proper coordination. The sixth and final reason is to collect the organizational knowledge and of the system and preserve it, this knowledge can then be used to modify the system (e.g. strip the system of unneeded functions based on the customer, purpose or new technology). (Vicente, 1999)

There are different paradigms and frameworks<sup>1</sup> that can be used for analysing a system. In the following chapters five paradigms and some frameworks belonging to each are presented.

#### 3.1.1 The cybernetic paradigm

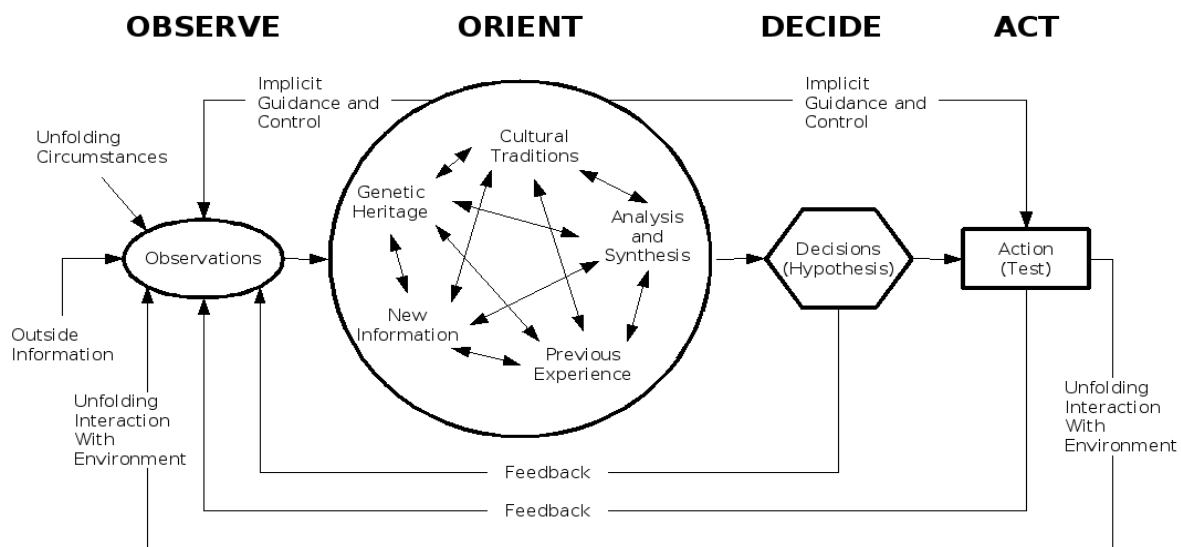
This paradigm is dominant within the field of C2 systems analysis. Cybernetic refers to a person controlling objects through computerized technology, the cybernetic paradigm seeks structure to model command and control; an operator has a goal, carries out an action, await sensorial feedback, compare with goal and then takes new actions (Stanton et al., 2008). This cybernetic paradigm is very technical; a scenario where functional parts exchange signals that can be described by mathematical formulae and used to determine the output a certain input together with previous output will result in (Stanton et al., 2008). Stanton et al. (2008) goes on to summarize the cybernetic paradigm as very focused on structural elements. The system is modelled through cause and effect and the deterministic nature of this means that a known input can be translated to a fully described output.

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<sup>1</sup> A framework is a set of methods and models used to connect associated aspects of an inquiry

Lawson's model of command and control is an example where the cybernetic paradigm is used. This model is based on a feedback loop where the commander senses the environment, processes the information, compares with the desired state and if the picture is not correct, decides to take a specific action and act. After the action is taken the cycle begins again and the new state of the system is the basis for new decisions. The problem with this model can be derived from the fact that it is so deterministic, it has troubles explaining how to deal with consequences of discrete events that are outside the limits and if the situation is uncertain, no comparison between actual and desired state can be done. (Stanton et al., 2008)

Another structural model is the OODA (Observe, Orient, Decide and Act) loop and this model is the most frequently used of the structural models. In Figure 8 the loop is shown, and in the picture we see the cycle of observe (what is going on) → orient (what are the available resources) → decide (how can the resources be used) → act (using the resources) and restart (Richards, 2003). Critics against this model states the fact that it loses the perspective of things not immediately concerned with the narrow slice of decision making process being studied, and hence cannot model total performance. (Brehmer, 2004)



**Figure 8 the four different stages of the OODA-loop**

Issues with the structural models are the deterministic nature of the models, if a system is modelled on some inputs and the output is measured, the model only describes a small part of the system. A system with human interaction can behave differently based on human cognition and actions, compared to a strictly physical process (i.e. a thermostat) (Rasmussen et al. 1994). The problem with cybernetic models are their inadequacy to model command, the approach models control and sees C2 as a means to react to a dynamic environment, this means that the cybernetic model is reactive ('event driven') (Stanton et al., 2008).

### **3.1.2 Network paradigm**

This paradigm is based on individuals, their relation to each other and the interaction between these individuals. In an organisational chart, the top-down hierarchy can be seen as command and the links between nodes reflects control (Stanton et al. (2008)). Stanton et al. (2008) summarizes the network paradigm as a more liberal paradigm compared to the cybernetic paradigm.

One example of this approach is the hierarchical task analysis (HTA), this popular model is used to achieve a collection, analyze and interpretation of system information concerning its performance (Annet & Stanton, 2000). This analysis is the umbrella for several methods which can be used to study specific scenarios and interaction when performing actions.

Compared to the deterministic approach of the cybernetic paradigm, this paradigm has a broader perspective and focus on links between entities. These links can be interactions or logical relationships. The broad view of the paradigm can make predictions outside well defined scenarios and thus more accurately describe a complex C4I system where, among other factors, interaction is an important factor to account for.

### **3.1.3 Agent models**

There is however a middle ground between the cybernetic paradigm and network paradigm, this middle ground consists of the agent models paradigm. Agent models are complementary to the cybernetic paradigm when a mathematical description cannot capture the whole behaviour of the system's non-linearity. The paradigm still models mathematical behaviour, but also takes into account complex behaviour by letting the separate nodes communicate.

### **3.1.4 Socio technical models**

The Socio technical paradigm is focused on the interaction between a computer and human. This paradigm sees the world as uncertain and chaotic, this means there have to be models taking into account scenarios no one ever thought of designing the system for. The model is thus more dynamic and adaptive. The models within the paradigm seek to model artefacts and human's interaction, to do this, environmental constraints affecting operator cognition needs to be modelled.

### **3.1.5 Event Analysis of Systemic Teamwork**

All models described have some advantages and disadvantages, although none of the paradigms have the generic properties needed to be applied to all C2 systems, one attempt has been made by Stanton et al. (2008) to find such a generic paradigm. The paradigm is called Event analysis of systemic teamwork (EAST). EAST takes into account actors who need to respond, teamwork and efficiency in technology for every scenario. One drawback of this method is the high degree of descriptive abilities. (Stanton et al., 2008)

### **3.1.6 Choice of Paradigm**

Table 1 presents a summary of the paradigms and frameworks presented in section 3.1 and after the table a discussion of what paradigm is suitable for this thesis takes place.

Paradigm	End Product Properties	Example models
<b>Cybernetics models</b>	Formal and structured parameters describing the C4I system and the response to known input.	Lawson's Model of C2 HEAT OODA Loop
<b>Networks models</b>	Properties of Networks	Hitchen's N2 HTA Social/ Prop Nets
<b>Agents models</b>	A gathering of structural parameters based on the interaction between units	WEA BOIDS
<b>Socio-technical systems models (STS models)</b>	What constraints are imposed on a operator's decision making and effort	Process Model Functional Model CWA COCOM

**Table 1 an informal view of paradigms, reworked from Stanton et al. (2008, p46)**

For conducting this study the socio-technical model has been chosen, although this is not the most popular for modelling situation awareness (the cybernetic is). The socio technical paradigm was chosen due to its focus on the synergy between user and the system, its ability to not only describe the system but analyze it from a formative (this approach will be discussed in section 3.2.1) approach. When seeking a model to give qualitative input to design, a formative approach is preferable (Vicente, 1999). Another key factor to this choice is the frameworks ability to support user decision-making and actions, which are an important factor for controlling complex sociotechnical systems (Vicente, 1999; Naikar, 2006; Jenkins, 2008).

### 3.2 Cognitive Work Analysis

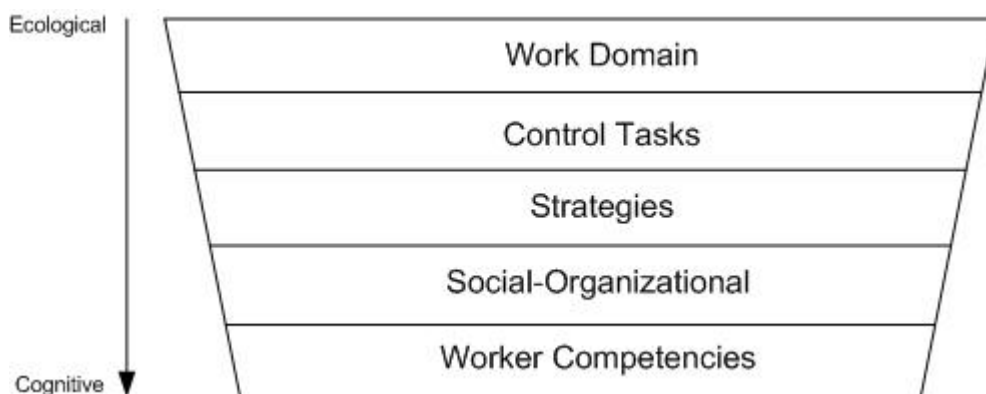
One type of sociotechnical models are the cognitive work analysis (CWA). The CWA should not be mistaken for a theory or a methodology, CWA is a framework that supports and structures the analysis needed when designing a flexible and adaptive system. CWA can be used to design several different systems, from large scale complex sociotechnical systems to small first-of-a-kind systems. This can be accomplished by using the formative approach which means considering all system's different degrees of freedom and constraints shaping behaviours of workers. In complex sociotechnical systems, designers cannot predict every scenario possible and thus it is important for the workers to be able to act dynamically and adapt their behaviour to unexpected situations. If a worker in a complex system can handle unexpected situations and act as a problem solver, the system will be healthy, effective and safe. As mentioned earlier, the CWA focuses on limitations and constraints on workers behaviour, mapping these constraints is the foundation to design a system. (Lintern, 2009; Vicente, 1999)

The CWA framework is currently very popular because of its ability to adapt and the different viewpoints provided to analyse a system. CWA has been used to analyse a number of systems with various purposes and within different domains. Some of the purposes and domains are; system design on naval systems (Bisantz et al., 2002), allocation of functions in military command

and control (Jenkins et al., 2008), system modelling in the medical field (Hajdukiewicz et al., 1998), air defence with flying radar interfaces (Naikar, Lintern and Sanderson, 2002) interface design and evaluation on process control (Vicente, 1999) interface design and information requirements specification in rail (Jansson et al., 2006) and information requirements and specification on air traffic control (Ahlstrom, 2005).

### 3.2.1 Different layers of CWA

When conducting a CWA it is wise to start with the ecological approach. This means ensuring compatibility with surroundings before adapting the system to cognitive attributes. When mapping ecological constraints there are several layers delimiting the area of discretion available to the operator, this has the effect that the analysis being conducted on several layers (Naikar, 2006). The Outline of the layers was first introduced by Rasmussen et al. (1994) and then restructured by Vicente (1999). In this thesis Vicente's structure of layers will be used due to its wide recognition in the CWA field. The different layers of CWA proposed by Vicente (1999) are work domain analysis, control task analysis, strategies analysis, social-organizational and worker analysis. This is usually the order which CWA is conducted in, this due to the fact of the ecological approach mentioned earlier. This order is illustrated by Figure 9 where the cones layer in the bottom inherits constraints from levels above; this is represented in the cone by narrowing the boxes (which represent degrees of freedom) for each level (Vicente, 1999).



**Figure 9 Dimensions delimiting the system edited from Vicente (1999)**

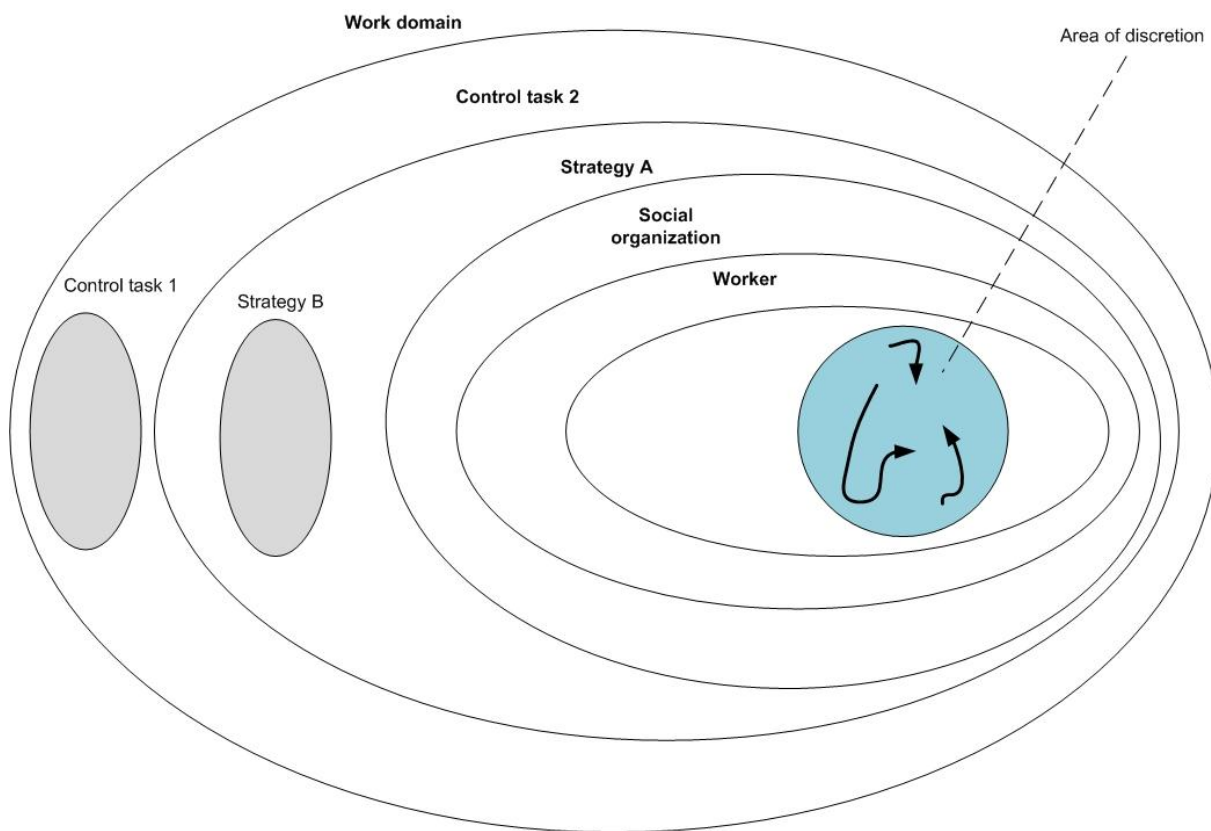
In the ecological approach to CWA, the analysis starts at the top with a mapping of the work domain constraints, next an analysis of what have to be done in the work domain is conducted and after this the strategies which can be used to carry out the control tasks. The fourth level of analysis is logically a level describing how these previously mapped conditions are divided between the actors within the system, and the final level explains what is needed of the worker controlling the system. (Vicente, 1999)

As stated earlier the different layers of CWA are a framework and depending on the scope of the study, different layers are prioritized. For example a study focusing on ecological interface design (EID) is often more focused on the work domain layer and an analysis of team design will subsequently focus more on Control task analysis and social-organisational analysis. (Jenkins, 2008)

Explaining the ecological approach is crucial for understanding the order needed to conduct a CWA (Vicente, 1999). To clarify the order and the formative approach, Figure 10 is used to



illustrate how the actions available to the operator are constricted by each level and how the constraints are nested within the work domain.



**Figure 10 A formative and ecological views of the constraints. The area of discretion is edited by the author to the original picture presented by Vicente (1999, p.116)**

A short explanation of the picture is based on the simple idea that every actor in the system are involved in activities to reach a higher goal, if the goals are reached, the system performs its purpose, i.e. for a worker to choose a strategy, information of what to achieve (control task) and the means available to achieve it (Work domain) must be known. After mapping this, we can move on to determine how work can be allocated within the strategy (social organization), and ultimately map the abilities necessary in a worker to successfully enact the purpose of the system. The area of discretion describes what degrees of freedom are left for workers to move inside. Control task 1 represents different tasks being carried out within the system and strategy B is used to illustrate different ways of enacting the task chosen (Vicente, 1999).

### **3.2.2 Work Domain Analysis (WDA)**

When conducting a CWA the WDA layer is an analysis used by most, this because of the analyze focus on the systems functional rather than the behavioural aspects of a system. The goal of a Work Domain Analysis (WDA) is identifying and mapping the system's physical (environmental), structural and intentional constraints of which are implemented for the system to fulfil its purpose. (Naikar, 2006) The foundation of WDA is a logical process where a problem solver describes the system with three questions; what is being performed, why and how (Jenkins, 2009). The answers



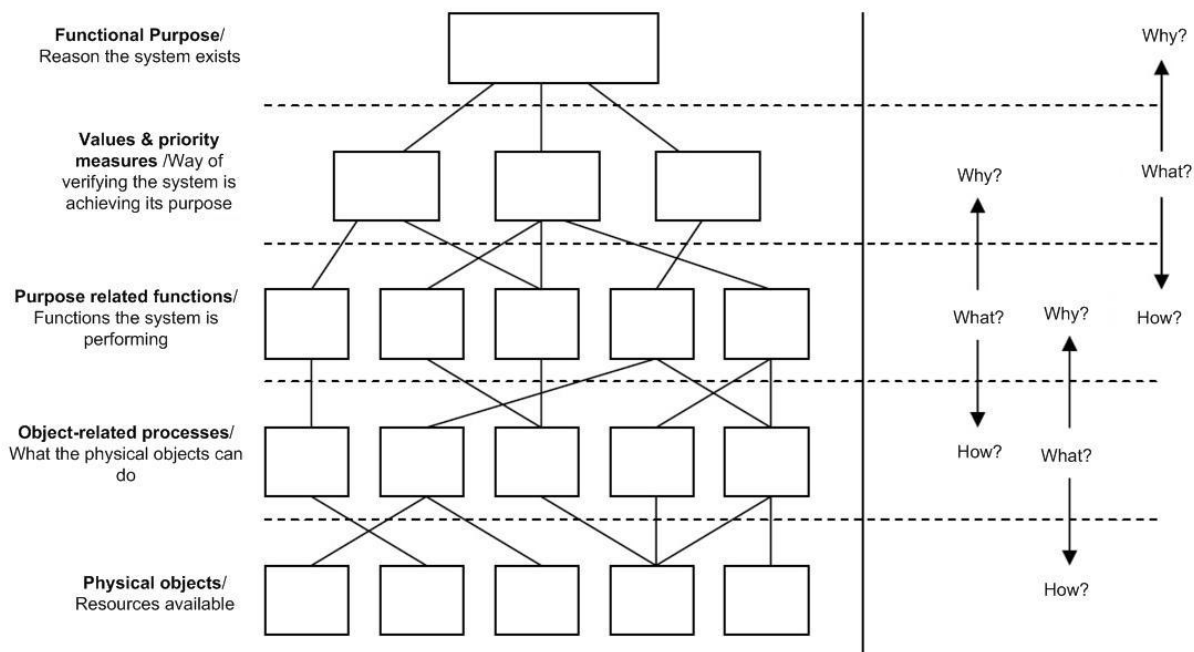
of these questions are then mapped hierarchically; this mapping will be described in the next section.

### 3.2.2.1 Tools for WDA analysis

When conducting an analysis of the work domain there are according to Vicente (1999) two different graphical representations complementing each other. The first one is called abstraction hierarchy (AH) and usually consists of five different levels; functional purpose, abstract function, generalized function, physical function and physical attributes. The hierarchical links between each level is categorized as means-end links, or put in another way how, why, what links as showed in Figure 11. These goal-oriented questions have the psychological advantage to all actors working in a domain. The questions in Figure 11 are used as a sliding scale, if a worker enters the hierarchy, the level will be the “what”-plane, and moving up one level, the reason why is visible. (Vicente, 1999)

The links between nodes can also be used to simplify complex systems for actors by showing the many-to-many mappings, one link could be used for several purposes and thus the links show what relations exists. (Vicente, 1999)

Although the *levels* described by Vicente (1999) is used for constructing the AH, the names of the labels are the ones proposed by Jenkins (2008), the advantage of the new labels is that they more accurately describe the information on each level, the labels do not however change the functionality or purpose described by Vicente. The labels and purpose of the level are located to the left in Figure 11; these labels will be used throughout the thesis.



**Figure 11 the abstraction hierarchy edited from Vicente (1999 p. 166)**

The AH representation is just a model with structural means-ends links, this kind of model is used due to its psychological benefits; by using higher levels to display an overall representation and

lower levels more detailed, the representation simplifies complex systems. This ability is not unique to the AH representation, what is unique is the focus on the systems purpose, when solving a problem one can simply start at the top of the hierarchy and make his way down the ladder and see constraints, this should support actors to; allow workers to perform a structured problem-solving with a overall map, this map allows actors to jump in to a level of abstraction necessary to provide a more holistic view of the problem and components. The AH also supports the understanding of the system and allows users to view in detail and easily “zoom out” to gain more perspective. The most important feature of the AH is its ability to let workers see the context of which an item can be used by following the structural links and thus shows the structural constraints of the domain when a worker is pursuing the goals. (Vicente, 1999)

The second graphical representation is the decomposition hierarchy (DH), where the system is represented by three different levels; the whole system, subsystem and components. This representation’s layout differs depending on the system being analyzed and typically it consists of the aforementioned three levels, although it can be expanded if the analysis explanation-value can gain from a more detailed division. The links between the levels is of the type part-whole (i.e. parts used to construct a larger entity, e.g. tires and engine is parts of a car). (Vicente, 1999)

To simply show the DH representation is often not necessary and creates more confusion than clarity, instead the AH and DH representations are put together in a two-dimensional abstraction decomposition space (ADS), this is a matrix representation of the two levels where the x-axis shows the decomposition hierarchy and the y-axis shows the abstraction hierarchy. In Table 2 below, the generic ADS illustrates how the framework of the tool looks.

Decomposition Hierarchy Abstraction Hierarchy	Total System	Sub-system	Component
<b>Functional Purpose</b>	Overall mission / Reason system exists	Command level goals	Agents goals
<b>Abstract Function</b>	Mission plans	Mission plans/ Way of verifying the system is achieving its purpose	Projected agent
<b>Generalised Function</b>	Course of action	Sub-system capability / Functions the system is performing	Agent capability
<b>Physical Function</b>	Mission status	Mission summaries	Agent Status/ What what physical agents do
<b>Physical Form</b>	Global view of battle space	Location of sub-system	Location of agents/ objects/ resources available

**Table 2 Generic ADS for a military domain adapted from Stanton et al. (2009, p. 40)**

Table 2 is a framework for modelling a system independent of actions. These tasks, action and activities are mapped in the next section.

### 3.2.3 Control Task Analysis (ConTA)

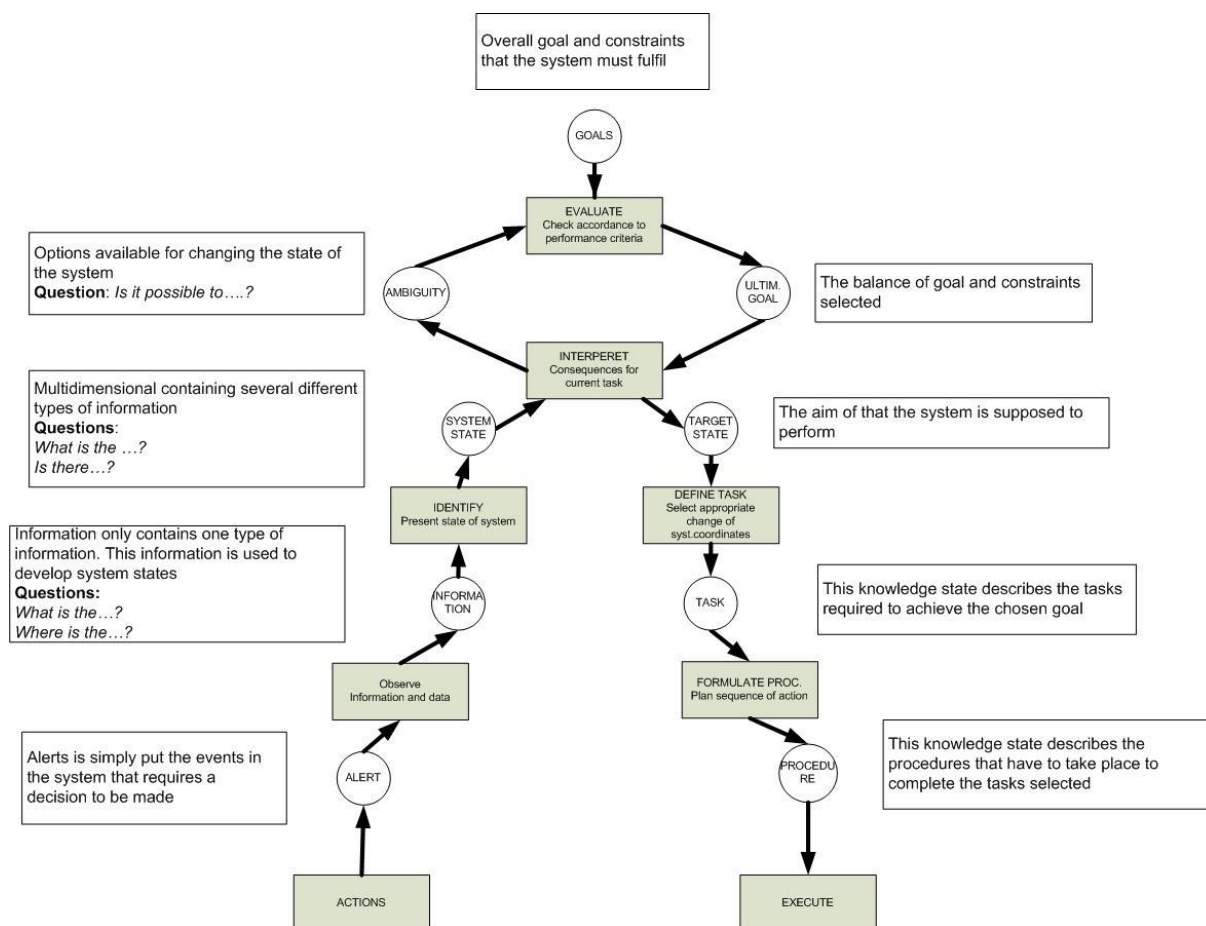
There is one classical type of analysis, which has been around for a very long time (earliest version dates back to the 1900s and Henry Taylor and was developed for more cognitive complex tasks in the 1960s) and is well tested in the field, the analysis is hierarchical task analysis (HT). This analysis focuses on goals and the physical and cognitive processes associated with the goal. The analysis divides the goal into sub-goals and tasks; this analysis therefore often leads to an analysis in the middle of a normative and descriptive approach (Salmon et al., 2010). When conducting a CWA Vicente (1999) advocates an analysis called control task analysis (ConTA). There exists research (Salmon et al., 2010, Stanton et al., 2008) indicating that both analyses gains from each other and used simultaneously gives a more holistic description of tasks within the system.

ConTA focuses on what tasks have to be done within the system; the analysis is not concerned with how or by whom the tasks are done. This analysis supplement WDA with the activities needed for the system to carry out its purpose. One goal of ConTA is supporting workers dealing with known and recurring situations. (Vicente, 1999)

There are three key points which can be used to describe ConTA; the *first* one is based on the fact that in most systems, there are several different ways in which a destination can be reached. This fact results in a demand of an analysis where *what* should be done is modelled (i.e. which input should result in what output), the modelling should be done without defining how or who should perform the activity. The *second* point of ConTA is to decide how the activity should be characterised; examples could be as work functions or situations. This information is then used to build a contextual activity template. The *third* key point focuses on the fact that decision-making processes needed for a specific situation or function can be used to further describe an activity. This mapping of decisions is usually done by the decision-ladder described below.

#### 3.2.3.1 ConTA Tools

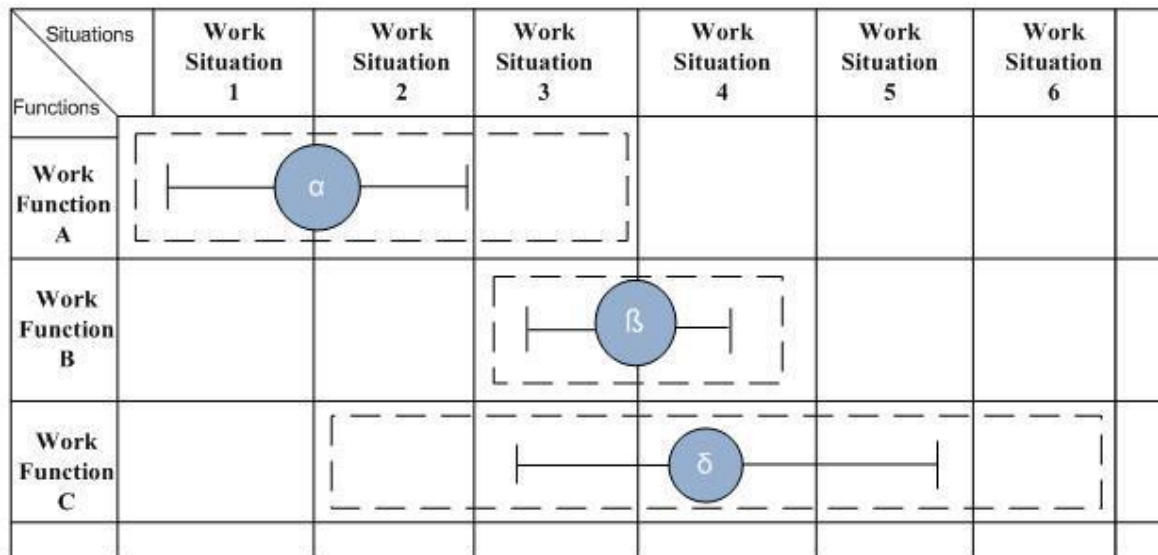
The decision ladder is a framework used to graphically map the cognitive decision-making progress for an operator performing a task. The advantage of using this framework is derived from the fact that the sequence of the nodes does not have to be linear; there can be leaps (jump from one circle to another, where a circle represents a state of knowledge) and shunts (shortcut from one square to a non-sequent circle, where a square represent an information processing activity). This tool is thus a suiting tool for description of an expert's behaviour when conducting a task in a complex system. (Vicente, 1999)



**Figure 12 Decision ladder edited from Rasmussen (1994, p.65)**

The decision-ladder consist of squares and circles, as described earlier, squares represent the cognitive function of information-processing and the resulting state circles represent a state of knowledge. This ladder describes how an operator processes a specific type of information and the resulting state of knowledge acquired from the information. Thus a task is represented from the first stage where an action might be necessary, the gathering of information (left side of the ladder), to the decision on what action to perform (right side of the ladder). The serial route in the ladder represents an untrained operator's (novice user) actions relatively accurate, though as described above, an expert's cognitive functions are harder to explain, the expert can take shunts and leaps, and their starting and end position can vary when they traverse through the ladder. (Vicente, 1999) A division of the ladder can also be done; the left side can be considered as observation of system state and the right side is focused on the planning and execution of decision (Jenkins, 2010).

There are different ways to construct decision ladders; one way used by Jenkins (2010) is to create a generic decision ladder. By listing all possible options and information that *can* be used in a decision step, the ladder becomes more generic and is not tied to specific actors or situations. Shunts and leaps are also left out, they risk complicating the diagram and thereby make it difficult to extract important information, and instead a different figure is used for mapping the relationships. (Jenkins, 2010)



**Figure 13 Contextual Activity Template edited from Jenkins (2009, s. 29)**

The ConTA is a figure representing activity by both work functions and situations. In this figure the function is independent from time and space, its defined by its content and situations on the other hand is defined by time and location, not the content (like recurring cycles, e.g. a train pulling into the station). Plotting these two functions on the x- and y-axis allows for activities to be analyzed in terms of the relationship between situation and function. By showing these two functions more of the system's constraints are revealed. The circles in the figure represent the function and the bar on either side of the circle represent in what situations the task normally occurs, while the dotted boxes symbolises in what situations the task *can* occur. In the figure, activity alpha can occur in both work situation 1, 2 and 3, but usually occurs in situation 1 and 2. This model has the potential to see what functions *can* be used in different situations and thus it has the potential to valuable input. The difficulties of applying the model are derived from the fact that analysing what different functions can be done is hard due to the fact that no one is using the functions in that type of situation.

### 3.2.4 Strategies Analysis (StA)

Where ConTA describes *what* needs to be done, a strategies analysis describes *how* an activity can be completed. There can be several ways of completing an activity; these ways are called strategies, to analyze these strategies, four important points need recognition. *Firstly*, StA is used to map generalized categories of cognitive procedures used to perform an activity, the procedures are often idealized and simplified for abstract representation of actions for easy understanding (Naikar, 2006). Vicente (1999) explains on page 9 the meaning the word strategies to describe "a category of cognitive task procedures that transforms an initial state of knowledge into a final state of knowledge." The strategy chosen by an operator will in turn reflect various variables, operator and situation (Rasmussen, 1986). This will result in a lot of different strategies, it is therefore important to make these strategies generic and categorize them (Vicente, 1999).

*Secondly*, it is important to distinguish between different types of strategies used to perform an activity, there can be written instruction, strategies based on experience (same learnt procedure as

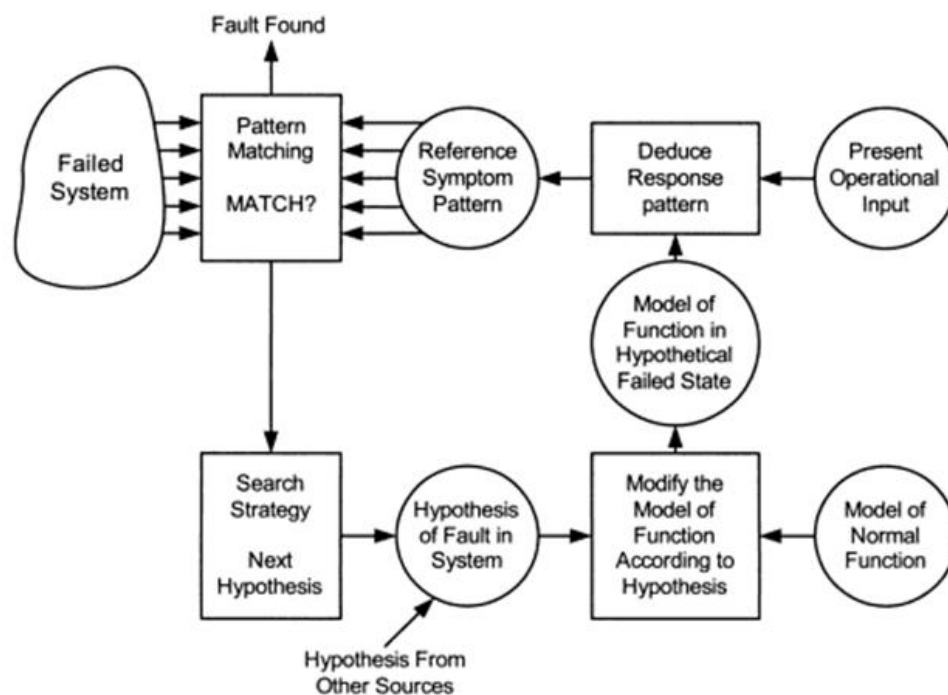
last time) and create a new strategy based on the understanding of system components. (Naikar, 2006)

*Thirdly*, when an operator performs an activity, she tends switch between different strategies. The criterions used to switch between strategies are based on the demands of the task e.g. time, cognitive strain and level of experience/knowledge. (Naikar, 2006)

*Finally*, it is important to find potential strategies not currently being used. The disregarded strategies could be to cognitive demanding and complicated to use with the current system, but could potentially make the system more effective if the right support was provided by the system. (Naikar, 2006)

#### 3.2.4.1 Strategies Analysis Tools

There are two different tools suggested by Vicente (1999) and Naikar (2006) for conducting a SA. The first one, an information flow map, was suggested by Vicente (1999) and is shown in Figure 14. This map is used to graphically present the information gathered from the analysis in a map where a detailed path of the workers action is presented.

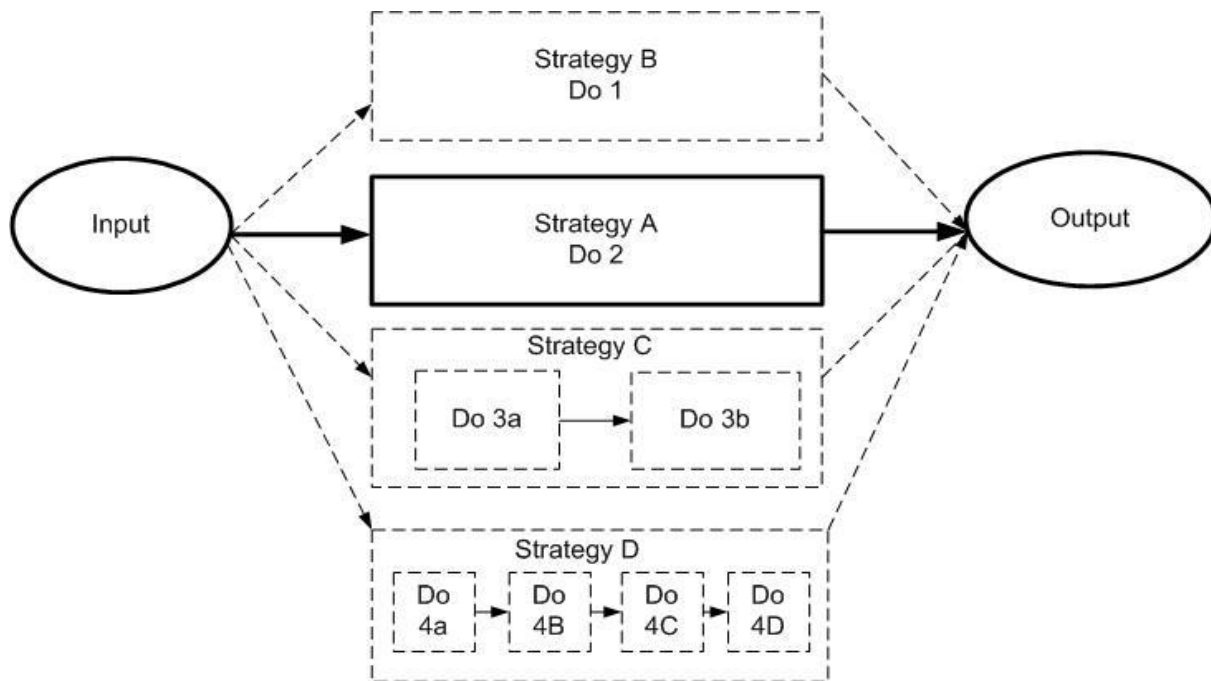


**Figure 14 Information Flow Map. Example of a technician's system-troubleshooting (Vicente, 1999, s.227)**

The reader should once again recognize the fact of this map not being a generic tool, but a framework in need of customization to a specific system (Vicente, 1999). In Figure 14 an example of information flow map (IFM) for a technician's troubleshooting in an electrical system. This figure is used to illustrate the complexity in an IFM and the degree of customization and details needed to construct a map.



The second tool for analysis was suggested by Naikar (2006); this framework for graphical representation is based on the analysis using simplified, idealized and generic categories of strategies and represents them through diagrams. A generic strategy diagram can be seen in Figure 15 below.



**Figure 15 Edited version of Information flow diagram from Ahlström (2005)**

The boxes in Figure 15 represent the strategies used when transforming input (start state) to a certain output (end state). This illustration of strategies to complete a task is based on the idea that details of actions and mental processes are not needed to analyze strategies at this early stage in the CWA. The boxes of strategies in Figure 15 should not be mistaken as a fixed path; workers tend to switch between strategies while completing an activity. (Naikar, 2006)

### **3.2.5 Social Organization and Cooperation Analysis (SOCA)**

When conducting a social organization and cooperation analysis (SOCA) the focal point is determining who can carry out work demands, i.e. can it be shared and/or distributed, and what is needed for work coordination. Rasmussen (1994) and Vicente (1999) describe in great detail how an analysis of SOCA can be conducted in a descriptive approach to analyze existing structure, not directed of how to conduct the analysis for design of new organizational structures (Naikar, 2006).

There are four cornerstones to take into account when conducting a SOCA; *firstly*, the level of organizational flexibility is important for the system's functionality, some systems need a high degree of flexibility to deal with unanticipated events. This fact results in one of SOCA's goals, to find *what* criteria are used to distribute work within an organization. Criteria discussed by Rasmussen (1986) and Vicente (1999) are; (1) Workload, distributing work to make sure an even load of work among actors. (2) Compliance, some regulations can't be changed due to injunctions. (3) Actor competencies, if an actor is more skilled and experienced performing a task, this may control the work allocation. (4) Reliability and safety, some actors may get specific tasks due to danger and their skill, experience and loyalty. (5) Access to equipment or knowledge, if an actor has the all required knowledge or equipment; this affects the choice of who gets the responsibility

to perform the activity. (6) Communication, sometimes it is important to minimize the amount of coordination and communication needed, this condition can result in a lot of work allocated to a single worker. The criteria added by Naikar (2006) are; (7) Availability, an actor may perceive the need for performing a task and solve it. (8) Enjoyment, preferences for tasks may govern the actor's choice for assuming responsibilities.

The *second* cornerstone of the analysis is to examine what factors can affect coordination of work, determining whether distribution of work is based on other factors such as; work domain, work situation, work functions, control tasks or strategies. In this particular case the decision ladder can be used to determine which task responsibilities are distributed to specific actors. The ladder maps what resources, information and coordination each operator needs to accomplish certain activities and what needs to be allocated. (Naikar, 2006)

The *third* cornerstone of the analysis is focusing on the communication and organizational structure used for coordination within the domain. The analysis should encompass different situations (i.e. a crisis, e.g. a war) and the consequences for the communication and organization. (Naikar, 2006)

The *fourth* cornerstone is based on the fact that organizations may change in real-time during the systems operation, this due to the fact off several different actors communicating and adapting to the context of the system. It is not the analysis's aim to discern the one best organization for every context, the aim is to find a method for conducting work, thorough distribution, allocation and organizational factors, which supports the dynamic, adaptive and flexible organisation needed to support the actor in dealing with unexpected situations. (Naikar, 2006)

#### 3.2.5.1 Social organization and cooperation analysis Tools

To graphically display the information gathered in this step, all previous models can be used. Annotations should be made on all models from previous steps to mark how tasks are allocated among workers. This is done by giving each actor a special colour and using this colour to mark what tasks and actions are performed by each actor. (Jenkins, 2008)

#### 3.2.6 Worker Competencies Analysis (WCA)

The focal point of this analysis is the tools and abilities needed by workers to operate efficiently within the system. This step in the CWA can be described with five abilities; the **first** is concerned with incorporating the previous phases of CWA and see what delimitations and required abilities needed to operate within the system. (Stanton et al., 2008)

The **second** ability of the WCA analysis is differentiation of cognitive levels of the worker. The levels used in the analysis are skill, rules and knowledge, this classification of cognitive work is also known as the SRK (skills, rules and knowledge) - taxonomy. *Skill* is when an operator works integrated and automatic with system to an extensive degree. The continuous loop of work with perception leading to an action is swift. The *rules* taxonomy is used to classify behaviour of a predetermined nature" if this is to be done → this is the way to do it", like following a recipe, the behaviour in this category is influenced by signals in the system determining predefined actions to be undertaken. *Knowledge base behaviour* is defined through a systematic reasoning and to solve



a problem based on the understanding of individual components. A mental image symbolising the system is often used to come up with new solutions. (Rasmussen et al., 1994)

The **third** ability of the analysis accounts for workers interpreting cues in the system differently and thus the information leads to separate actions and cognitive behaviour of the kind previously described. Figure 16 shows the three cognitive modes for interpreting information received from the system; signs, signals and lastly symbols. In the same order as the previously described SRK-taxonomy, *signals* help the skill-based behaviour with quantitative indicators signalling easily understood and continuous information. *Signs* support rule-based behaviour, when a certain cue in a form of i.e. a tone is produced by the system a worker performs a standard action. Finally *symbols*, supports knowledge based-behaviour, these symbols can be formal instructions describing the systems properties and support the user understanding and allow for changes in the system (like a conversion table). (Vicente, 1999)

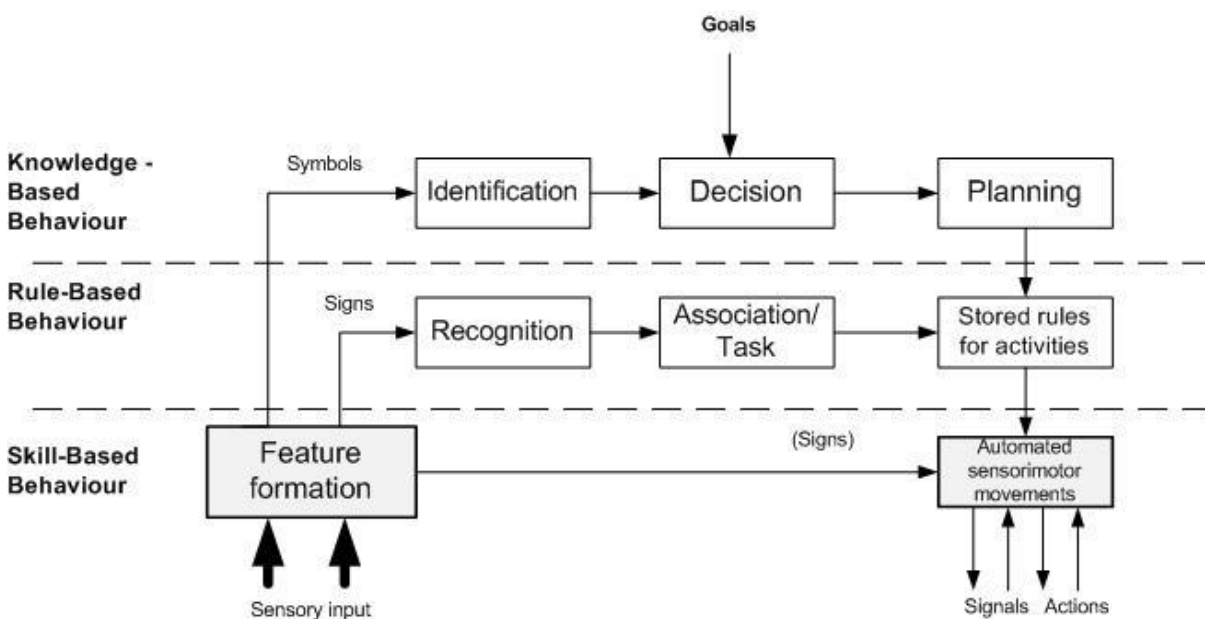


Figure 16 Simplified model of the SRK-model taxonomy of the human performance categories. The arrows show the information paths, adapted from Vicente (1999).

The **fourth** level of the analysis recognizes that the way information is presented to the worker can influence what kind of behaviour being activated. As described previously signals, signs and symbols have the ability to influence behaviour adapted to solve a task. There are however other factor affecting behaviour which have to be addressed for the presented information to be effective, these factors can be workers level of expertise and level of reflection on task demand and execution.

The **fifth** and final ability of WCA is taking all above abilities into account and design a system allowing workers to use the lowest cognitive level for the tasks to be completed swiftly, efficiently and without so much effort from the workers. Higher levels of cognitive thinking also have to be supported if the worker is to be able to handle unexpected situations.

### 3.2.6.1 Tool for conducting a WCA

One way to analyze how to design a system is the "user centred system design" (UCSD) – approach, this approach was used by Jansson et al. (2006) in the aim of developing interfaces for train operators. The approach is based on the idea that design decisions must be adapted to fit within the specific conditions of the system and the best way to find these conditions is by letting an expert of the system (user) explain them and using workshops to determine the best way of designing for all above mentioned conditions.

A different tool which can be used in the WCA analysis is the Skills, rules and knowledge taxonomy (shown in Figure 32) (Kilgore et al., 2006). The aim of this tool is structuring the analysis to encompass all constraints in a skill, rules and knowledge based perspective. This information is then graphically displayed in a table describing the information processes used and the resulting knowledge state obtained by the worker. This table can be used as a checklist of the types of cognitive behaviour to take into account when trying to understand the strategy and what information is needed when designing. The information from this table can also be used when training workers to operate the system. (Kilgore et al., 2006) In this thesis the author uses the latter tool due to its values in representing a system's constraints.

## 3.3 Connection between analysis and design

This section provides the reader with information of how CWA can be used to offer input to design of a new system and in Chapter 7 the implications on the design from the CWA conducted on air surveillance and adapted to the Compact C2 system is presented.

The goal with a design of a complex system is to give an operator a continuous control and overview, to receive early warnings of disturbances, support to determine the correct tasks (and their sequence and in what situation to use them) and also have effective support for alternative operations. (Vicente, 1999)

A "good" cognitive environment strives for a design that supports; presentation of dynamical surveillance data, allowing the operator to have complete control. Display all essential information for completing a task when a task is being conducted. Show detail and overview of the system at the same time. Support current operation, view historic states and plan for future tasks. Display relevant courses of action and solutions. Minimize unnecessary cognitive workload and adapt the system for the work. (Jenkins, 2008)

As mentioned earlier CWA is a framework for analysing a system, the output of this analyze can be used as input to different models of design. A common method (i.e. Dinadis & Vicente, 1999) for design is "Ecological Interface Design" (EID), also called Functional Interface Design. Instead of displaying all sensor output on a display and allowing the worker to interpret them with a huge amount of cognitive effort as a result, the ecological interface design seeks to create the overview with sensor information displayed logical, showing underlying processes, how the system changes between different states and delimitations of the control options. The method is expected to produce more information in the system, although in a way adapted to work, and thus not increasing the cognitive load for workers. This is done by integrating the information in a natural way, which allows workers to find relevant and critical information about specific situations.

When designing a workspace or interface Lintern et al. (2004) have listed four specific key points to consider;

1. *Information demands* refer to determining **what** information to display.
2. *Information Layout* strives to create a backbone and decide **where and when** the aforementioned information should be displayed in relation to other information displayed.
3. *Visual representation design* aim to decide **how** components should be represented to enable operators easily can comprehend the presented information.
4. *Navigation and linking* is intended to decide **how operators move** through all information and link together associating information.

These key requirements for designing a system are met by the CWA and its phases;

The first phase of the analysis (WDA) shows, as described in chapter 4.3, the most essential functions and what information they need to function. The analysis also shows the connections between functions. The analysis gives a foundation to base the design of linkages, navigation and associations needed to gain information.

The second phase of the CWA (the ConTA) is used to reveal the consecutive paths of accessing information and thus help to decide the type of access, linking and navigation needed when operating within the system.

The third phase (SA), used for mapping different paths of the control tasks discovered in the ConTA, shows further how information should be presented for logical linking, navigation and access.

The fourth phase (SOCA) is designed (as describe earlier) to map the type of communication and coordination that takes place between different workers and automation. This ability allows for information on what types of communication links are used and how.

Finally the fifth phase (WCA) describes the type of behaviour which is used by a worker when conducting a work task. This information can then be used to decide how the correct information should be displayed.

To illustrate how the CWA output can be used to influence design, the Table 3 is used. Support for design decisions are shown in the column at the right.

Analytical phase	Tool	Goal	Relationship to previous phases	Systems design Interventions
<b>Phase1 Work domain</b>	Decomposition tool Abstraction Hierarchy	Keyword: <b>Why</b> . Analyze the underlying structure or ecology of the system. 'The physical and intentional constraints should also be analyzed to find all constraints regarding the systems functionality.	This phase is updated from insight gained in consecutively phases of the CWA analysis. These tables are continuously and iteratively updated.	Sensors Models Database
<b>phase 2 Control task</b>	Contextual activity template Decision ladder	Keyword: <b>What</b> . Activities and tasks emanating from the system's purpose needs to be identified. Knowledge states and cognition (information processing) for these tasks are analyzed.	Some recurring tasks were identified during the WDA, when some generalized functions were examined.	Procedures Automation Context-sensitive interface
<b>Phase 3 Strategies</b>	Information flow map	Keyword: <b>How</b> . This phase should as the name states identify all strategies used to solve tasks.	Recurring tasks from previous analysis were used to find general classes of tasks to analyze.	Dialogue modes Process flows
<b>Phase 4 Social organization</b>	Information flow map	Keyword: <b>by whom</b> . Identify who should perform a control task, or if the task can be allocated among a team of actors.	The information maps come from the strategies analysis and they are used to find responsibility in an organization with several actors.	Role allocation Organizational structure Communication Links Coordination Links
<b>Phase 5 Worker competencies</b>	SRK inventory	Keyword: <b>by what means</b> . This analysis is based on the skill- , rule- and knowledge-based behaviour. Through the different behaviours it identifies competencies and techniques.	During the control task the first to columns of this inventory was filled when the decision ladder was created. All control tasks discovered in previous phases will be subjected to this analysis.	Selection Training Interface form Information requirements

**Table 3 summary of the CWA framework and its implications to interface design**

In this case there already exists an operational system and one of this thesis's aims is to redesign the interface, which means the design approach used in the thesis will be evolutionary. The design

of the new system will thus inherit many design decisions from the old system and with these decisions comes constraints affecting the design of a new system. (Vicente, 1999)

### **3.3.1 Interface design guidelines**

A system should minimize the work aimed at evaluating the state of a system and executing commands for achieving the goal. Operators of the system evaluate and take actions in relation to their mental model of the system; hence for a design to be well suited to the operators needs, the design must support the creation and use of the operator's mental models. This support and creation of mental models is enabled through making parts visible to users, together with allowing the operator to understand what actions are possible with the parts. (Jenkins, 2008)

For an understanding of how work is carried out in the air surveillance division, the CWA framework can be used and give some understanding, but without basic guidelines for interface design, it is difficult to give suggestions for design.

When designing a system with the operator in focus there are some general guidelines that should be followed. Benyon et al. (2005) have compiled a list of factors to consider;

**Design a system supporting the mental model (enable easy accessing, learning and remembering of the system). This is done by;**

1. Transparency; it is important that the interface is displaying important information, this allows the user to determine the systems status and what functions in the system the operator can use.
2. Terminology; Symbols and language should be adapted to the users, depending on their background the terminology should be adapted for the use to feel familiar with the system.
3. Affordance; all functions and symbols should make clear what they do.
4. Consistency; the design must be consistent. It is a lot easier to handle a system where the functionality and layout does not change depending on the window.

**The users must feel like they are controlling the system**

5. Help users with logical and easy navigation to move within the system.
6. Feedback; clear information of the results of an activity
7. Control; if something is happening and its progress cannot be changed, the user needs information of why it is happening, who is controlling it and allow for operators to seize the control.

**The users should feel safe when using the system**

8. Limitations; block users from making errors, disable some functionality.
9. Resilience; If an error is made, there must be a quick and effective way to recover

**The users should feel at ease with the system**

10. Joviality; the system should be designed to be friendly and polite in the dialogues and interaction
11. Appearance; the system should feel modern and appealing
12. Flexibility; users should have the freedom to personalize the system after their preferences and support multiple paths for completing a task.

Now that the method for analysing a system has been chosen and the frameworks potential to generate suggestions for interface design has been established, the focus will shift towards a detailed explanation of how the analysis was carried out.

## 4 Method

*This chapter presents the methodology used as basis when conducting the study. First an explanation about the validity and reliability takes place, and then the method for conducting the CWA analyze is explained.*

Without a clear scientific approach when performing a study, the author risks an unclear picture of where he is heading (Ejvegård, 2009). The scientific approach chosen is deductive; the theory yields an analysis of empirical results which leads to a discussion and finally the thesis's conclusions.

When performing a study, there are a number of methods that can be used, e.g. experiments, surveys and case studies. The chosen method should reflect the thesis's scope, problem and limitations of resources, i.e. the conduction of a study with only one researcher, with a limited amount of time and resources, Bell (2000) states that a case study is most suitably and it is also the one chosen for this study. The case can be composed of a single situation, one person, a whole organization or a system (Patel & Davidsson, 2003). The advantages of a case study lies in the depth of which a small piece of the problem can be analyzed to find its influences and drawbacks of the study is the difficulties generalizing beyond the specific case. (Bell, 2000) This drawback has the consequence that a complete and detailed description of the case must be presented, to allow the reader to assess the applicability to her own purpose (Lincoln & Guba, 1985). This has the implication that this thesis may not be reproduced when developing a different system.

There was a need to find a similar system to the Compact C2 system since the Compact C2 system is new and lacks customers to interview, has no interface to analyze and no operators using the system. A system which has the same functions and more is the C2STRIC system used by the Swedish military. The Compact C2 system is planned to be a more light-weight configuration of the C2STRIC system and therefore an analysis of the C2STRIC should gain insight into how work in air surveillance is carried out with the C2STRIC system as a tool.

### 4.1 Collection of data

In this chapter there will be a discussion about reliability and validity, where reliability will be defined as how reliable the measurements are (i.e. given that nothing has changed externally, measuring should give the same result every time) and validity will be defined as the correctness of that being measured (i.e. whether the question measures relevant information (Bell, 2000).

The data will be gathered through an empirical holistic approach because of the approach's ability to grant the researcher with information of specific circumstances surrounding the problem (Åsberg, 2001). This approach gives a more comprehensive image of the problem. The drawback of the method is the time it consumes and consequently the researched case should be well delimited. (Holme & Solvang, 2007)

There are two different types of data, primary data and secondary data. Primary data is data collected personally by the author, while secondary data is collected by someone else with another



purpose (Kumar, 2005). In this study, the more reliable primary data was collected during interviews and observations. Secondary data on the other hand was collected through organizational documents, books and articles.

When conducting a study with the empirical holistic approach it is hard to follow any kind of consistent way to make sure the qualitative data collected are valid. There is however a guideline to triangulate over several sources of information in order to gain a correct description. The sources used to triangulate can be documents, interviews and observations. (Patel & Davidsson, 2003) These guidelines have been used throughout the thesis and the following chapters describe how the sources were used.

#### **4.1.1 Literature**

The literature in this study was used to build the theoretic framework and by gathering information about previous research in the subject, the author was able to determine what area of research and what kind of problem to focus on.

#### **4.1.2 Organizational documents**

As mentioned earlier, the purpose and origin of all the case company's documents that were used in the thesis was analyzed to understand why and in what context they were created. According to Patel & Davidsson (2003), in order to maintain high validity and reliability, the questioning of the secondary source information is important.

The organizational documents (consisted of manuals, requirements, HMI guidelines and instructions) was used to gather a basic understanding of the system, automations, the roles, tasks and goals of operators in air surveillance division. These formal instructions were also used for helping with creating the last part of the CWA, the formal task description in the SRK framework. The manuals also gave provided something official to compare with the operators mental image of the air surveillance work.

#### **4.1.3 Interviews**

The study began with an exploratory phase where low standardization and a low degree of structure on the interviews were used to develop an understating of the company's work and to develop in-depth questions. When speaking of the structure of an interview, a structured interview means a small space for answering, while an unstructured interview gives the respondent more space and low degree of standardization means that the questions can change during an interview based on gained information (Patel & Davidsson, 2003).

The Second phase of interviews was concerned with collecting more specific information, so semi structured interviews were conducted with engineers explaining the program functions, physical attributes of components, officers explaining the systems overall purpose and organization, while operators and instructors explained strategies, processes and worker competencies. Respondents from the explorative phase were in some cases interviewed again to follow up on interesting information.

The respondents were chosen based on their current positions within the system to gain insight in different parts of the system to help give a more holistic view of the complex system. Several interviews were conducted to correct for subjective descriptions. Six (subject matter experts) were

interviewed (with follow up-questions) and five operators were interviewed (Five ASOs, with follow-up questions) with a semi-structured interviews and during the interviews with ASOs they were occupied with performing system tests. The operators performing system tests at the same time as being interviewed can have affected the answers in a negative direction, although several follow up-questions were used to maintain a high validity.

The questions varied depending on the respondent and the information they hold, this for obtaining a high degree of validity (ensure gaining correct information). During the second phase of the study, the questions designed based on literature and the explorative phase of the study, were continuously analyzed and reviewed to determine whether they measured what they were supposed to and gave valid information. The questions used in interviews can be seen in Appendix II: Interview questions. All questions in the appendix were asked to the interviewees and the follow-up questions are not listed as they were designed to uncover more specific information from answers.

During interviews notes were taken and a tape recorder was used with respondent's consent, the tape was used to verify correct interpretation and ensure no information was ignored, thus increasing reliability. The recorder could have affected answers during interview, reducing validity; the author did however not note any such effect and considered the reliability to be important enough to take the risk of decreased validity. In a few interviews with SMEs and operators holding classified information the author judged that the tape recorder could affect interviews in a negative direction, instead notes were taken and all relevant information were transcribed immediately to ensure validity of information.

#### **4.1.4 Observations**

In the explorative beginning of the study, observations were used to collect information about the system in action. This technique were used to gather information of normal procedures and behaviour in the system, and chosen due to its capacity to gather information without respondent's memory or willingness to share information affect the result. In the first phase unstructured interviews were used to gather broad information about the system, when basic understanding was acquired, more structured observations were used to learn about detailed behaviour in certain situations. During all observations, notes were used to help remember key observations. The aim of the observations was to uncover more diffuse characteristics of work in the domain, these characteristics was for example principles, values, interaction- and communication-patterns.

Observations were made on three separate occasions when operators visited the C2STRIC systems at the SAAB-factory for evaluating the system. These opportunities did not allow for screens to be recorded and only notes were taken due to classified information. The evaluation days consisted of searching for errors, controlling repaired and changed functions and try all functions in the system. The work carried out was not representative for work in actual settings due to many missing tools, malfunctioning systems and different tasks than those carried out in operational mode. The observations was used to gain insight of what happens in the systems and used for a targeted observation in normal conditions. When operators evaluates the system at the factory, only the C2STRIC system is evaluated, all tasks of air surveillance that are not tightly coupled with the C2STRIC system is omitted.

One field observation was made to see operators in their normal working conditions with the full-scale C2STRIC system and see actual settings and work within the whole domain. In this field trip a whole day of work with two different operators working in shifts was observed. The classification of sensitive data meant that no recordings could be made and only one visit was allowed. The observation was made on one day when a new way of working was tested (shared responsibility), the information gained was therefore not of normal working conditions, instead of a team with three operators there was only one. This affected the analysis of social organisation. To counteract with this new way of work, interview questions were used to allow the operator to explain what was different from normal conditions.

The observations was carried out in person and the respondents were informed of the author being there and in what purpose, which could have affected their performance and thus, reducing the reliability and validity of the information gained. No behaviour to indicate this was noted.

#### *4.1.5 Scenario testing*

For testing functional chains covering multiple functionality and components, scenarios<sup>2</sup> were used (see Appendix III: Scenarios), these scenarios were not representative for live operation. Instead the scenarios were used to show how operators deal with different kinds of situations and allow recording and playback of the operator actions for a detailed study. The scenarios were based upon material from the operator's education (and the observations that were made in the explorative phase and the field study) and evaluated and checked for validity with SMEs at Saab before being used. The scenarios were designed to follow a story line where a workers actions varies in its use and the whole cycle of an activity is recorded (Desikan, 2006). The story line was to first spot a track and then track, adjust sensors, indentify and report the track.

The purpose of this study was to measure and analyze certain tasks and how they were performed within the system. The aim was to receive information and explanations to tasks that would otherwise be difficult to receive by verbal explanations. The way to collect information was to use a non-confidential system and capture the screen with a program to record actions in the system, due to the thesis limitations of time, no video recordings of the operator was made. By capturing the screens and allowing them to verbally explain what they were doing a comprehensive walkthrough was carried out. Difficulties setting up the non-confidential system to work as operators was used to, meant that no flight plans could be used. Due to time-constraints and limitations of available operators the scenarios were used with two operators, and the system reconfigurations meant that only one recording could be made. The recording was used by the author to go back and view what tasks the operator carried out within the system and analyze actions not verbally explained.

Only two MROs participated in the tests. This reduced the grade of generalizations that can be made by the scenarios. To gain more reliability, the operators were asked a series of follow-up questions about how they perceived the differences among operators interacting with the system.

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<sup>2</sup> When functional chains of testing components and functions with realistic test cases are used to evaluate a system. (Desikan, 2006)

## 4.2 Summary

As Figure 17 shows, the study starts with the thesis and then takes two general directions. First of all a literature study and explorative interviews were carried out to gain a basic understanding of the problem. After this phase relevant theory was chosen and used to produce interview questions and structure for the more targeted interviews and observations of the C2STRIC system and Compact C2 system. After interviews and observations the material was structured into the CWA framework. In the analysis the two systems are compared for differences and design implications for the new system are presented. Conclusions about the use of the CWA framework are presented in the last chapter.

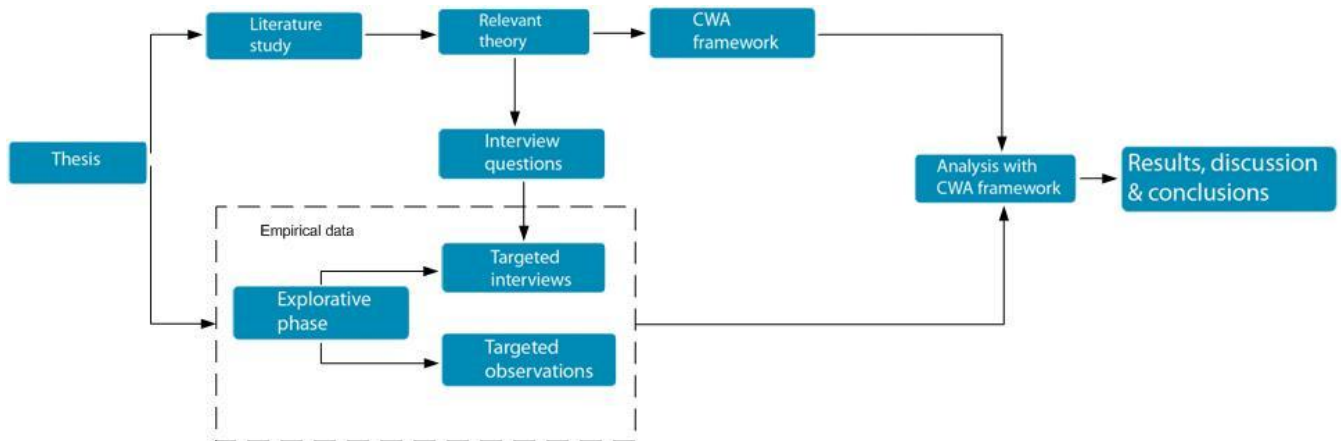


Figure 17: Description of the research path

Scientific approach	Deductive
Research structure	Case-study
Type of data	Qualitative (Literature, interviews & observations)
Data collection methods	Empirical holistic

Table 4: summary of the scientific approach

## 4.3 Structuring empirical data of the C2STRIC system with CWA

The CWA framework presented in the theory chapter were used together with an ecological approach to a formative analysis; this means that elements in the environment influencing the system and shapes the actions of the operator are mapped and analyzed. As explained in the theory chapter, the analysis consists of five different stages; work domain analysis, control task analysis, strategy analysis, social and organizational analysis and worker competencies analysis. An explanation of how these analyses were used to structure the empirical findings is provided in the next five sections. According to Vicente (1999) it is important to initially put a lot of effort in the work domain analysis. During the structuring of information transcriptions were used, these transcriptions are, however classed as confidential material and will not be a part of this thesis (for Saab employees the material is available through the mentor, Peterson).

### 4.3.1 Work domain analysis

The timeframe available has led to some constraints of how detailed the analysis of the system will be, other factors affecting the focus of this thesis were the availability of operators (the Swedish air surveillance operators available for interviews) and the level to which the thesis's results can be used across several of Saabs systems (although the systems used for air surveillance has some similarities, the focus has been the C2STRIC system and the Compact C2 system). To summarize only the air surveillance work in the C2STRIC system is studied and no detailed descriptions of planes and radars will be undertaken in this stage of the analysis. Delimitations made in WDA will in turn affect all subsequent layers of analysis and thus it is important that the delimitations made are consistent with the scope of the study.

The decomposition hierarchy tool described in the theoretical framework was used to initially create a coarse understanding of the whole system and its parts. All parts of this diagram was built and validated by traversing between levels and asking every node two questions;

- Is the node constructed by all nodes below?
- Does the node build all nodes above?

After the decomposition tool, the abstraction hierarchy (AH) tool was used to gain a holistic image of the work domain. For constructing the AH, a strategy presented by Vicente (1999) was used. The strategy proposed that the analyst should start at the top of the layers and first determine the systems functional purpose and then start at the bottom to determine what components the system contains. By filling the top and the bottom it was possible to fill the three middle layers.

For a basic understanding of an AH of a military domain literature from authors engaged in military domains and CWA was consulted (e.g. Naikar et al., 2002; Lintern et al., 2004; Jenkins et al., 2008; Jenkins et al., 2010). The authors inspired much of the work but as more information was acquired from interviews, the AH was updated iteratively and the language adapted to local expressions gathered from interviews (e.g. SME 4 expressed the importance of availability and used that word), this was done for an increased understanding among the audience at Saab.

Controls of language consistency were conducted for every level to make sure the language used measured the same things (e.g. what should be maximized respectively minimized for fulfilling the main purpose). Furthermore every level was built iteratively using control questions and traversing between nodes, the questions used are means- end questions, illustrated in the theory chapter (see Figure 11). Several different AHs was created and evaluated on their potential to provide information to a design of a new system. One very large AH was constructed and placed in Appendix IV: Complete AH and a simpler version were used for the sake of clarity for presenting the system in chapter 5. For the sake of clarity in this thesis, an overview of the whole domain of air surveillance was constructed and no detailed information was gathered of each function in the system.

The information used for constructing the AH and ADS was gathered through interviews with subject matter experts (SMEs) and corporate documents describing the system. This approach supported by Jenkins et al. (2009) and the reason for using SMEs is the reliability in this phase is a

key ingredient, if the information gained is inaccurate the errors will follow through all other phases.

#### **4.3.2 Control task analysis**

This analysis was, as described earlier, used to map the information processing activities of the control tasks presented in the work domain. The decision ladder was applied to perform the mapping of the operators processing of input to output. The general functions of the AH were used to identify the different control tasks occurring in the system. The control tasks were used to construct the decision ladder with the help of interviewed operators.

The theory chapter described that the hierarchical task analysis could be used to help the analysis with CWA. Due to limitations of time the HTA were not used during the task analysis.

A model by Jenkins (2010) was used as guide when constructing the decision ladders. The difference between Jenkins's model and the model presented in the previous chapter is the fact that Jenkins excluded all shortcuts. Omitting the shortcuts is done in order to simplify the diagram (all possible connections would make the diagram very confusing).

The information used to fill the decision ladder was gathered through interviews with five operators, scenario testing and observations of work in the domain. When constructing the DL diagram a blank decision ladder was filled in with annotations. The subjects were asked to recollect the information with the help of examples evaluated by two SMEs at SAAB (some of the examples were also used for scenario construction, under the identification heading in Appendix III: Scenarios). For transferring the model to a more generic model, not based on the examples, interview questions directed to find additional information was used (e.g. what alerts could be recognized and start a cycle of action). This DL model does not show specific connections and the relationship between the information; instead it shows possible states and elements and another model shows the relationships and states omitted by the generic decision ladder. Due to late interviews there was no time for additional interviews where the generic DLs could be discussed and validated.

Two generic DLs was created, one for the identification process and one for the optimization of radar stations. The identification process was chosen to show an in-depth task analysis with several decision ladders. The identification task was chosen due to its importance and its possibility to provide insight to the new Compact C2 system of how the identification process should be carried out. And the generic decision ladder of the optimization process was used to show a different perspective of the tasks that must be carried out by the operators, thus showing the potential for another more exhaustive analysis of this task.

The contextual activity template was not used to structure information due to time limitations.

#### **4.3.3 Strategy analysis**

The information flow maps were used to graphically display the different strategies used to solve tasks. One strategy map was used for an overview of strategies within the system and a more specific flow map was used to show the identification process in more detail. The strategies were then analyzed in terms of cognitive strain, type of situation and overall effectiveness.



The second flow map was evaluated and iteratively updated after feedback from operators of how work with identification was carried out in the system. When Figure 28 had reached a mature state, it was evaluated in a group with five operators during an informal meeting and was updated based on the discussions in the group.

Two strategy diagrams were used to summarize the information flow maps. The strategy diagrams were created for both the optimization of radar stations and the identification process.

#### ***4.3.4 Social organizational and cooperation analysis***

Information flow maps were largely created by observations of air surveillance operator's work in their domain. By observing operators actions in the domain, task allocations, responsibilities and coordination between human and automated procedures when completing a task was identified. The delimitations from the work domain to only study air surveillance and a deeper analysis of the identification process governed the analysis in this section as well.

Strategies identified during the strategy analysis were used in this analysis, this together with decision ladders was used to mark who could and typically did perform certain tasks. During this phase, a critical approach together with a comparison between human and automation's information processing capabilities was used to analyze the organization. The reason for this approach was to find an optimal distribution of the information processing activities between humans and automation. When conducting this analysis and dividing jobs between computer and operator it is important to take into account that human operators needs to be a active (have qualified duties and make decisions), not suddenly thrown into action when something goes wrong.

The SOCA analysis in this thesis is relatively basic. Interview questions has been used to gather some understanding, but due to low availability of operators to interview and only one short field visit with a new way of working, there are still many blind spots of how work is allocated and carried out in the organization.

#### ***4.3.5 Worker competencies analysis***

When structuring information into the SRK tables certain attention was directed towards finding different types of behaviour. The SRK diagram was filled with information from interviews, observations and the screen capture recording. The first two columns were filled with information from the decision ladders created during earlier analyses, and the last column was filled using manuals and interviews with operators. Again the delimitations to only study the identification process in-depth and an overview of the optimization process affected this analysis as well.

#### ***4.3.6 Summary of the CWA framework***



Analytical phase	Tool	Goal	Relationship to previous phases	Systems design Interventions
<b>Phase1 domain Work</b>	Abstraction Hierarchy Abstraction Decomposition Space	Keyword: <b>Why.</b> Analyze the underlying structure or ecology of the system. The physical and intentional constraints should also be analyzed to find all constraints regarding the systems functionality.	This phase is updated from insight gained in consecutively phases of the CWA analysis. These tables are continuously and iteratively updated.	Sensors Models Database
<b>phase 2 Control task</b>	Decision ladders	Keyword: <b>What.</b> Activities and tasks emanating from the system's purpose needs to be identified. Knowledge states and cognition (information processing) for these tasks are analyzed.	Some recurring tasks were identified during the WDA, when some generalized functions were examined.	Procedures Automation Context-sensitive interface
<b>Phase 3 Strategies</b>	Information flow map	Keyword: <b>How.</b> This phase should as the name states identify all strategies used to solve tasks.	Recurring tasks from previous analysis were used to find general classes of tasks to analyze.	Dialogue modes Process flows
<b>Phase 4 Social organization</b>	Annotations on all previous tools	Keyword: <b>by whom.</b> Identify who should perform a control task, or if the task can be allocated among a team of actors.	The information maps come from the strategies analysis and they are used to find responsibility in an organization with several actors.	Role allocation Organizational structure Communication Links Coordination Links
<b>Phase 5 Worker competencies</b>	SRK inventory	Keyword: <b>by what means.</b> This analysis is based on the skill-, rule- and knowledge-based behaviour. Through the different behaviours it identifies competencies and techniques.	During the control task the first to columns of this inventory was filled when the decision ladder was created. All control tasks discovered in previous phases will be subjected to this analysis.	Selection Training Interface form Information requirements

**Table 5 : Summary of the CWA framework, as seen in previous chapter (structure of table adapted from Kilgore & St-Cyr, 2006)**

#### **4.4 Structuring empirical data of the Compact C2 system with CWA**

Interviews with the development team of the Compact C2 system and a limited amount of documentation showed three different configurations of the new system. When analysing the new system the focus was directed towards the air surveillance configuration, this due to the similarities with the air surveillance work of the C2STRIC system. Interviews were carried out with three SMEs and corporate documents were used.

When the information was gathered of the configurations, the CWA framework was used to structure the information. The structuring resulted in a AH representing the air surveillance work in the Compact C2 system.

The Compact C2 was still in the beginning of its development and had no users or organizations to use as input for design. Instead interviews with the team behind the idea of development were carried out to gain an understanding of potential customers and what demands and requirements existed for the system.

#### **4.5 Tools used for creation of CWA figures**

During the work of creating many different versions of figures and iteratively update them, a special CWA tool was used (THE CWA TOOL (2007). HFI-DTC., Yeovil Somerset UK. The tool and examples are the collective work of Bessell, K., Farmilo, A. J., Hone, G. N., Jenkins, D. P., Salmon, P., Stanton, N. A., Walker, G. H and Whitworth, I., M.).

After the iterations were completed, the AHs and information flow maps were created through Microsoft Visio. Visio was more powerful and allowed for more free use of boxes and looks (this was especially needed for the AH in Appendix IV: Complete AH ).

#### **4.6 Design**

When the analysis of the C2STRIC system was complete, analysis of how the new Compact C2 system began.

The design of the new system is evolutionary, the C2STRIC system is the basis and some functionality of this system will be stripped. The reason for using the old system is because it is more cost-efficient than developing a totally new system from scratch and it is important to customers buying the system to know that the system has been used operationally and it works.

Using the understanding gained from work in the CSTRIC system, a few directions of the design and further analysis was identified. The basis for these different factors was derived, both from the general guidelines of a system (presented in section 3.3.1) and the information structured with the cognitive work analysis framework.

# 5 Air surveillance work and the C2STRIC-System

*This chapter starts with an analysis of the work domain and then in descending order, ConTA, SA, SOCA, and finally WCA.*

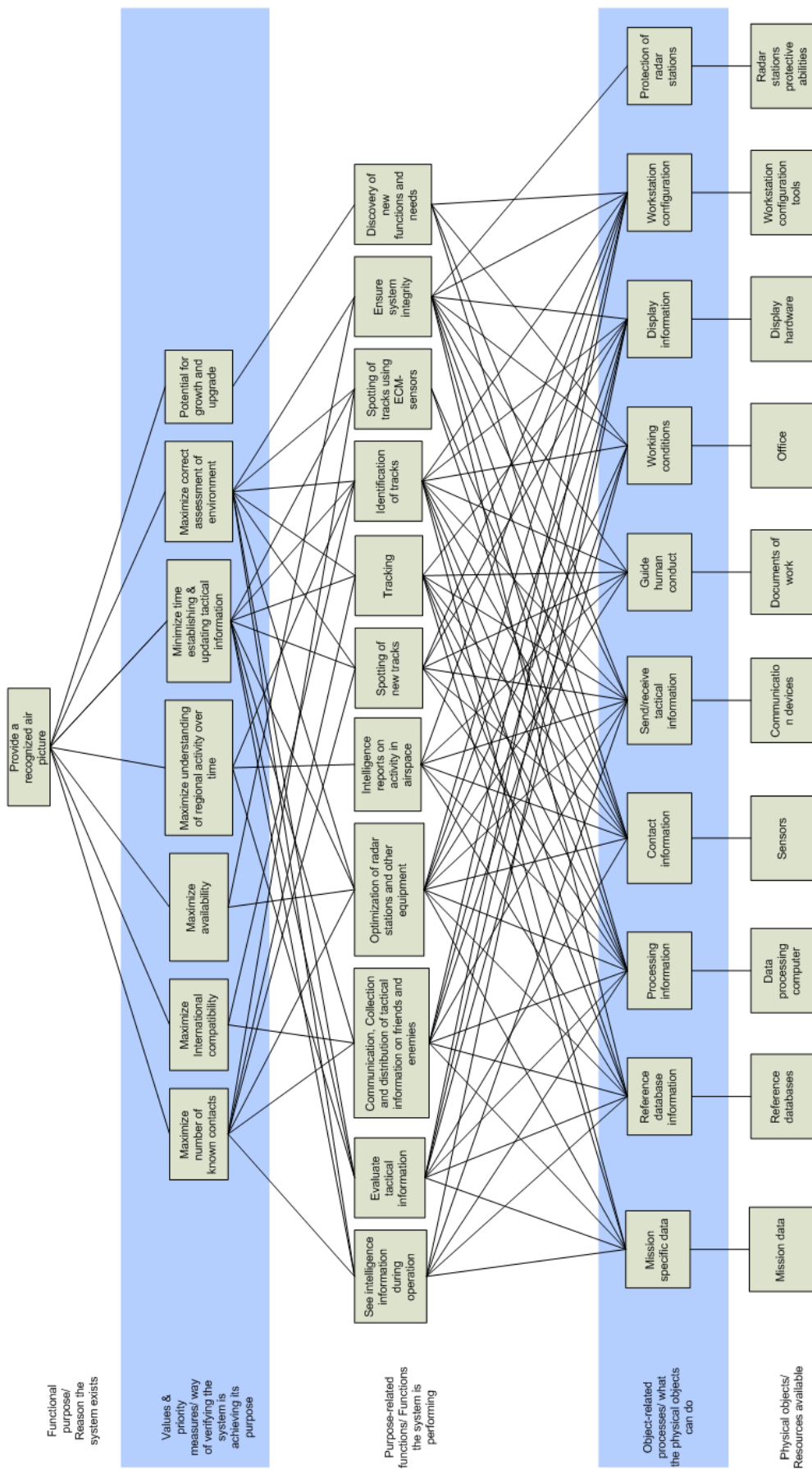
## 5.1 Work Domain Analysis (WDA)

The first stage of the analysis is a WDA of the air surveillance work in the STRIL battalion. The first tool for analysis is the abstraction hierarchy, where all components and their connections are presented with structural means-end links.

### 5.1.1 Abstraction Hierarchy (AH)

Due to the fact that the AH presents the reader with an understanding of how the system works and the links between components the description the AH will be done thoroughly.

On the highest level of the AH (see Figure 18), the overall system goal is presented and for the air surveillance section it is to provide the RAP. This picture can then be used as decision support by several different actors to compile their situation awareness with; the compilation and using of the RAP to take actions is outside the scope of the analysis. Figure 18 is a simplified version of the complete AH produced (see appendix 3).



**Figure 18 AH Air surveillance domain**

#### 5.1.1.1 The functional purpose

As we can see in the AH-model the functional purpose of the air surveillance work is to provide a RAP. This picture is then the basis for the situation awareness other actors defending Swedish airspace have.

#### 5.1.1.2 Values and priority measures

**Maximizing the number of known contacts** is a key factor when using several sensors for creation of a comprehensive RAP. Everything in the airspace should also be represented by a track on the RAP. One aspect of this is that the responsibilities of air surveillance are to utilize all sensors to achieve radar coverage over the whole country.

Another abstract function of the system is that it must be *internationally compatible*; the system should be adapted to communicate with other countries, especially if the system is deployed abroad. This abstract goal has the effect that the system must have the ability to send information and receive information, which means following international standards.

**Availability** in the system plays an important role; if a central/radar station/console is not operational, another can take its place and the system is always online and compiling a RAP. This redundancy also covers hardware and software, the system is designed to withstand an element malfunctioning.

**Maximizing the understanding of how the RAP changes over time** is an important way to see what activities are “normal” and what kind of information is of important enough for intelligence reports.

Endsley (1995) describes situation awareness as a tool to gain advantage over the enemy by enabling the capturing of the initiative. Endsley (1995) further states two key factors to capture the initiative with the situation awareness as the foundation; a correct assessment of the environment and quick assessment of the incoming information, this is also true for the air surveillance work in the C2 system. Early awareness, real-time updating (**minimize the time of establishing and updating tactical information** is very important where old information can cause the ground air defence to attack friendly forces or not finding an enemy) and qualitative information (**maximize correct assessment of the environment**, where the information in the system must be reliable) of tracks is very important to create a good RAP. These two goals are therefore found on the second level of the AH.

The last part of the systems abstract functions is to record what **potential there is for growth and upgrade**, this is important for keeping the system updated for the RAP to improve even more. Improvement of the air surveillance work is a continuous process where functionality and processes is added iteratively. This function is also used in this diagram to gather information of where potential of new system functionality can be found.

#### 5.1.1.3 The purpose-related functions of the system are;

When an operator tries to gain an understanding of what is expected to affect their surveillance sector, it is important to **see intelligence information during operation**. This factor can help the

operators assess if there is any needs to adjust sensors to accommodate for a very interesting activity in Swedish or international airspace (e.g. extra coverage of an exercise).

An ***evaluation of tactical information*** is always done in the air surveillance work, this evaluation is done for several reasons, one of the reasons is to understand what is going on in the airspace and if it is “normal”. Another is to maximize the use of sensors when something important occurs and a third reason is to understand when to take specific actions (e.g. send fighters to intercept an approaching flight). It is important for the operators to be active contributors to situation awareness by presenting all known information in the RAP.

***Collection and distribution of tactical information*** on friends and enemies from several different sources takes into account how important it is for the system to be able to receive information from different kinds of sensors and centrals. This function is necessary for sharing tracks between both Swedish and foreign military sources, also between many different types of sensors. This is also an important factor when several centrals are cooperating. Cooperation between centrals is when two centrals are operational at the same time and when other countries are cooperating in producing a RAP. Cooperation could be messages being sent (free text messages containing instructions), pointers added to the map (adding special symbols on the map indicating interesting events, e.g. a man in the water), marked areas (for example dangerous locations such as minefields and flight corridors for planes to fly through without being attacked by anti aircraft defence).

***Optimizing radar stations and other equipment*** can be done to ensure that the sensors are providing correct information. Without this function operators cannot guarantee that all information is displayed correctly, sometimes the weather or malfunctions makes it necessary to adjust the sensors. The goal is a complete radar-coverage over Swedish airspace. Another factor of this is configuring other equipment (e.g. Link 16).

Compiling ***intelligence reports of activities in airspace*** is a function where the information of interesting flights is recorded. Other countries air activities are recorded, together with information concerning flights with special permits to enter Swedish airspace.

The ***spotting of new tracks*** is a function to detect if there is a physical object moving in the airspace, this is important for the discovery of new tracks; the process where the system recognizes patterns within plots was explained in section 2.3.1

***Tracking*** is an important function for following what is moving within the RAP and evaluating if all information on the track is correct.

***Identification*** of tracks is based on a classification system where an aircrafts intentions and nationality plays a big part. This was described in section 2.4.

***Spotting of new tracks using radar- disturbing equipment (ECM)*** is an important function of the system, if an aircraft uses the offensive tactic of jamming equipment, they probably tries to hide something of great importance, one function of the system is to give a bearing towards these disturbances.

**Ensuring system integrity** is one of the functions performed within the system; it is aimed to make sure all stations are operating. This is done by taking them into cover when an enemy is attacking one of the radar stations.

The last function of the system is to **discover ways to improve the systems function and needs** for keeping the work with air surveillance updated and helping operators work to provide a correct RAP.

#### 5.1.1.4 The object related processes are;

**Mission specific data** is used to give the whole battalion information of current missions and priorities that should affect daily work. This data can also contain information from intelligence, air tasking orders (ATO, a 48 hour plan for the battalion to carry out).

**Reference database information** refers to the manual information, flight plan information, telephone numbers, environmental information and weather conditions. This information is used to search for more information and put surveillance information about a track in a context using environmental information.

**The information processing** is done (by computers using TDFE, MST and to some extent workers) to; process information from sensors (multisensory tracking, triangulation, conflict resolution, etc.) and provide measures of manipulation of data processing settings. Analysis of incoming data is a process, using several sources and combining their information to a single picture where only one track represents an object in the air (also called correlation) is one of the processing activities that take place in computers.

The fourth object related process in the AH (Figure 18) is to provide **contact information**. This essential process provides all information from the systems sensors. Measure what and where target is located in terms of height, coordinates and type is one of the most important functions of the system. The information derives from both the PSR and SSR stations. One type of the information used here is ESM (Electronic warfare support measurement); this type of information consists of bearing and categorisation to radio signals, jammers and radar energy emitted from tracks radar. This process also shows information of radar coverage.

**The sending and receiving of tactical information** with other countries and centrals, when two centrals are connected in a network it's important to be able to communicate with each other. Communication within Swedish forces means that communication with JAS, ground air defence, radio surveillance intelligence, and other units who has a telephone or radio connection. This also includes communication with ATCs and smaller airfields. Cooperation between stations also requires good communication. One example of this is the switching process when cooperation between centrals is being carried out, there is a need to handover the RAP to another central; this means that all information from one central must be correctly sent and responsibilities handed over to the other central. Dividing airspace and responsibilities is based on the fact that cooperation between centrals and operators within a central must be carried out with high precision and no faults can be tolerated. The same demands for correct information exchange goes for international cooperation with tactical data links. The information exchanged contains; PPLI (Platform of participants and system status (e.g. fuel status) is a process where all information of



participants in the network sends their information of their position and status) information, secure voice communication, secure text messages, exchange of RAP and control of radar quality.

***Guides to human conduct*** are information used to discern behaviour; many of the ordinary tasks have detailed descriptions of how an operator should solve them. This box also contains political information such as ROE (rules of engagement), policies and repair manuals guiding actions.

***Working conditions*** is not self explanatory and often a forgotten fact when modelling a system; this is a factor that should not be forgotten in a military system where the systems usage conditions can vary much. Seating, light, distances and intercom systems all affects the systems functions. For example, the close positioning of operators in teams makes communication within the team surveillance very effective.

***Display information***, this process is supposed to graphically or through text show the operator the essential parts of the airspace in Sweden. Display data is a process to actually show where objects in the sky are located to the operator through a screen, but also show internet information, intelligence information and telephone connections. This is the process allowing graphical information to be displayed (e.g. internet information from the reference databases).

***Workstation configuration*** is a big category where several different processes are mapped against several physical resources. This configuration can involve modification of radar stations to make sure they are providing correct information, examples of this is putting radar stations into protective mode (allowing them to go underground) or providing extra energy to certain sectors.

***Protection of radar stations*** is a process where the stations can be put in protective mode to preserve the functionality of the stations in a situation where there is a threat against a stations capability to transmit.

#### ***5.1.1.5 Physical objects;***

***Mission specific data*** is the type of data directly connected to current mission, one example of this type of data is the communications definitions on the TID (touch input display). This category also contains ATO data.

***Reference databases*** are the general category of the collected databases used to gather specific data to make informed decisions. In this category there are flight plans from several systems, manuals for easy explanation of the system functions, maps for environmental information, weather forecasts for a understanding of the conditions in the air (information is given through reports), internet and telephone catalogues (used for storing numbers to airfields, police, ATCs, etc.). The flight plans database is not a single system, much of this information is spread around. Flight plans is comprised of several systems; CMFU is an internet based service where all flight plans from Europe is collected (not just the ones concerning Swedish airspace). DBU 607 is an old system providing flight plans for aircraft passing through Swedish airspace. The new version of flight plans function is already built into the C2STRIC as a window.

***The data processing computer*** is comprised of several different functions; TDFE (Track data fusion engine) is a tool developed by SAAB for fusing (correlating) tracks from different sources; active, passive and other systems. The TDFE is made up of MST (multi sensor tracker) and TCFM

(Track Correlation and Fusion Module). A short description of the TDFE is that each sensor each gives a bearing towards a target, with several radars a position can be triangulated and the computer coordinates all information so that the system understands that all stations are seeing the same target. This computer also maintains and continues to store data on all tracked aircrafts and have an interface for the operator to configure the data processing. The processing computer is the brain of the system, it summarises all information and provides the system with its intelligent analysis. The information can be height, speed, position or heading. The data processing computer delivers quality of the tracked aircraft, together with position; it also triangulates bearing towards jammers and takes into account an imperfect globe and the maps properties when mapping the aircraft.

The *sensor* category consists of PSR (primary source radar), SSR (secondary source radar) and ESM (electronic warfare support measures). There are two main categories of sensor types, SSR and PSR. SSR is the simple technology and is dependent on the aircraft having a working transponder and “answering” with its transponder code when the SSR radar asks where it is, to pinpoint the location several SSR radars asks and measures the distance to contact and thereby triangulating the location of the aircraft.

There are a few different boxes of individual types of sensors, these could have been fitted to one broad category, however since the radars all have different abilities and these abilities have an impact on the workers actions and strategies if the station malfunctions, they could not be categorized as one. There are a few different types of PSRs delivering the information to the system; Radar system 860, 870 and 890, civilian radar stations and signal tracking systems are also used to in air defence. Anti-aircraft defence with radars can be connected to receive and send information to C2STRIC. The stations varying abilities; for example, the 860 –station is based near the coast and can see low flying objects and the other stations are based inland to spot high-flying targets.

There is also a plane used for airspace surveillance, it is called the air surveillance radar 890 (also called FSR 890 or Erieye). The radars coverage is 450 KM on each side and has signal surveillance equipment and IFF equipment and ESM capabilities. The plane holds five multi roll officers who identifies and sends information to the ground through the C2STRIC’s link 16. The purpose of the surveillance plane is to improve the ability to discover low flying threats and supporting surveillance where radar-coverage is temporarily reduced, helping with electronic capabilities (e.g. detecting signals and categorizing this for more information when setting an uncertain identity) or when it is important to improve radar coverage in a specific area. Another source to gather ESM information is to contact FRA (försvarets radioanstalt). Electronic Surveillance measures (ESM) is used to identify the type of plane and origin by means such as listening to the planes radar and determining what type of radar it is, and listen to radio activity to determine what nationality and type of radio-transmitter it is.

*Communication devices* within the system is the tactical data links, headphones, fax, external intelligence system and the countries backbone net (in Sweden it is called Sendnet). Link 16 is a tactical data link used for transferring information between different systems connected in a

network. The link was developed by the United States and was later used by its allies and NATO. the information travelling over this network is; air tracks, surface tracks, land tracks/points, subsurface tracks, reference points, emergency points, acoustic bearings, EW (electronic warfare e.g. a radar jammer) bearings/fixes, areas (polygon, line, rectangle/square, circle/ellipse), secure voice (encrypted voice communication) and PPLI (Precise Participant Location and Identification). Secure voice communication, this part is currently not implemented into the system; there is voice communication, but not secure voice communication through link 16. But since one of the goals is to be internationally compatible the ability to transfer information secure through link 16 is being considered. Other communication devices are headphones with microphone / telephone / touch input display (for calling and storing numbers).

***Documents of work*** is a category consisting of several types of documents, there are; political information such as rules of engagement, detailed operating procedures guiding when something unusual but standardized should be conducted, and equipment manuals describing how to use the system and repair equipment.

The ***office*** box consists of several different components. There are intercom, seating aspects, lightning and toilets, restrooms, eating facilities. The intercom consist of a headset with microphone, it is not used within the air surveillance group due to close seating. The light operating conditions allows for a high contrast screen and no movement of the station allows for a mouse to be used for interaction with the system. Positions close to the screens allows for a very high resolution of the screens (makes information small).

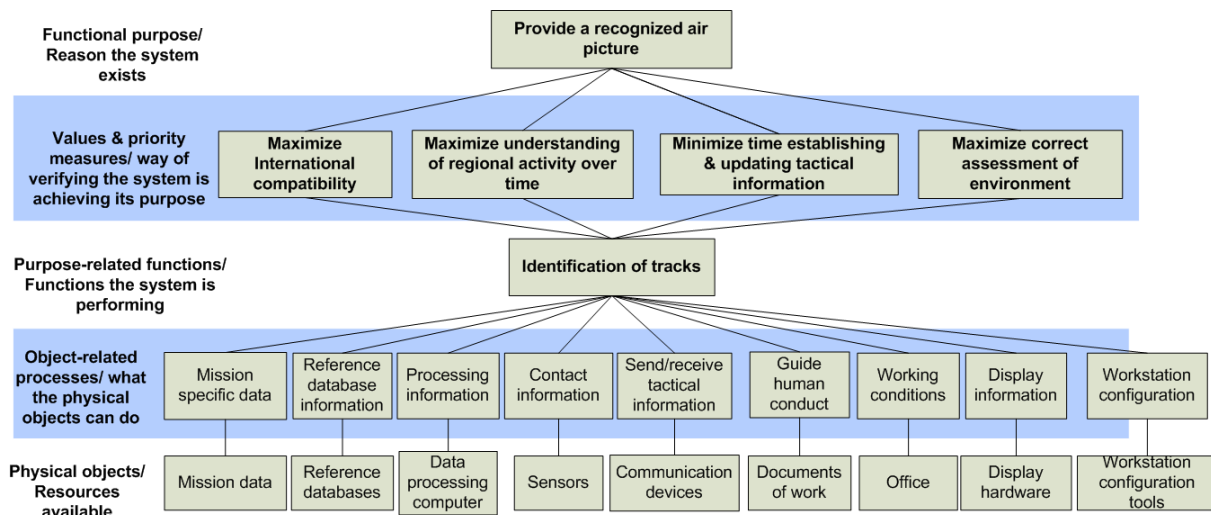
***Display hardware*** is mostly self-explanatory. The type of screens used for the C2STRIC system is two 30” inch widescreens placed close together. The surveillance system is older and uses a 17” inch screen. The communications panel with touch input is 10” inch. Lastly, the extra screen with an internet connection for displaying flight plans is a 22” inch widescreen.

***Workstation configuration tools*** consists of several types of configuration tools; interaction tools (mouse, keyboard, TID and quick buttons) are used for interacting with the system, work stations (all equipment collected for easy interaction), settings for display (to choose what to show on the screens).

***Protective radar stations abilities*** are; selective transmission of energy to specific sectors (to hide from radar seeking missiles or avoid detection), No transmission of energy (standby, this can be done for saving resources and not risk detection by hostile elements) and lastly place the radar station underground is done to protect stations from an incoming attack.

#### ***5.1.1.6 One example of links between levels***

There are a lot of links and describing all links between levels would take up to much space and time, to illustrate how the links in the AH are created the identification function can serve as an example.



**Figure 19 AH of the identification function for illustrating the links of a specific function**

Starting at the top of the AH we have the overall goal, to provide a recognized air picture. Doing this requires some sub-goals found on the level below. The **first** one is to maximize international compatibility, this is needed for the recognized air picture to be compiled with data from more actors other than Swedish and also affects the identification process, and for international cooperation certain rules apply when setting identities. The **second** sub-goal is to maximize regional understanding over time, this factor is important for proving the recognized air picture, mainly because of the need to understand what is normal in the behaviour of aircrafts and what abnormalities there are. For the understanding of regional understanding to increase a good identification process is used, all aircrafts are identified and classified. The **third** sub-goal is to minimize the time of establishing and updating the tactical information, the recognized air picture needs to be updated as close to real-time as possible. For the information to be established and registered on many system a identification is needed, especially if the users of the RAP is parts of the link 16 network (most of the information on the link 16 network is not sent, only identified aircrafts are sent). The **fourth** sub goal is the maximization of a correct assessment of environment. This sub goal is used to make sure that all information in the RAP is correct and that the information is reliable. One factor to achieving this is to make correct identification of all objects in airspace.

When using the identification as the top of the last three levels a new chain arises, here the identification process is the box that answers the question why. And this level requires multiple of the object related processes that answers the question what. *Mission specific data* can be used to gather information about what activities will be happening in the airspace and thereby help with the identification of tracks. Also data concerning communication definitions helps with understanding what connections are available for identification support. Reference database information supports the identification with flight plans, maps, external telephone numbers and weather conditions. *Processing information* helps by allowing information to be processed, the TDFE helps by making sure only one track represents one aircraft, the contact database makes sure that no tracks are lost and there is a good history of the track for determining past behaviour of a track. Contact information is the most important part where a position, height, identification codes, etc. enters the system. The box with the title *send/receive tactical information*, is provides the identification function with tactical information from tactical data link, this information can be

identities and identification information of own forces that are participating in the network. Since this category consists of ways of transmitting voice externally, faxing and the system for sending and receiving intelligence information, the box is imperative for the identification function. *Guide human conduct* represents guides that can be used to gather information of operating procedures (e.g. how to set a specific identity), but also what identities can be set during the current alert level (during a low alert level, the identity is not allowed). *Working conditions* affects the identification process by supporting an open communication within the team, positioning of workers at a station where they can perform their functions. Displaying information puts the information gathered from all sources (contact information, RAP, telephone connections, internet information, etc.) on the screens to allow the operator to use it. *Workstation configuration* allows the operators to interact with information within the systems.

An example of how the components can work together will now be presented; The flight plans in the bottom of the hierarchy (inside the box of *reference databases*) is used for analysis of data; when a plane wants to take off from an airport the pilot hands in a flight plan and receives a code which is put into the transponder. When a radio tower (SSR radar from the *sensor* box) on the ground asks the aircraft who and where it is, the plane sends the transponder code. When a track is received in the C2STRIC system, the transponder code (IFF-code) is displayed in a label next to the plane, if all information is correct and the flight plan exist inside the C2STRIC system matches the code provided by the transponder, the aircraft is automatically linked to the flight plan and identified according to the flight plan information.

### **5.1.2 Abstraction Decomposition Space (ADS)**

As mentioned earlier this tool is used to display the AH in its subsystems and give a clear picture of what boxes are built of what components. Whereas the AH only show means-end links the ADS show parts-whole relationships. The last two levels in the AH is mapped to the component level of the ADS, this is done because they are the parts that the levels above consists of.

Decomposition Abstraction	Whole system	Subsystem				Functional object			
Functional purpose/ Reason the system exists	To Provide a recognized air picture								
Values & priority measures/ way of verifying the system is achieving its purpose		Maximize number of known contacts	Maximize International compatibility	Maximize availability					
		Maximize understanding of regional activity over time	Minimize time establishing & updating tactical information	Maximize correct assessment of environment					
		Potential for growth and upgrade							
Purpose-related functions/ Functions the system is performing		Spotting of new tracks	Identification of tracks	Spotting of tracks using ECM-sensors	Ensure system integrity				
		Discovery of new functions and needs	Tracking	Intelligence reports on activity in airspace	Optimization of radar stations and other equipment				
		Communication, Collection and distribution of tactical information on fri	Evaluate tactical information	See intelligence information during operation					
Object-related processes/ what the physical objects can do						Mission specific data	Reference database information	Processing information	Contact information
						Send/receive tactical information	Guide human conduct	Working conditions	Display information
						Workstation configuration	Protection of radar stations		
Physical objects/ Resources available						Mission data	Reference databases	Data processing computer	Sensors
						Communication devices	Documents of work	Office	Display hardware
						Workstation configuration tools	Radar stations protective abilities		

**Figure 20 ADS Air surveillance**

In the bottom two fields of the ADS at the level of the functional object, the physical objects and its process are placed. These functions are placed here because they are the parts by which the more general functions consist of. These more general functions are place on the level of subsystem and use one of more of the components on the functional level. In the upper left corner the whole system is placed, and due to delimitations, the whole system level is to provide a recognized air picture and this whole system is composed of the functions found on the subsystem level.

### 5.1.3 Summary of the Work Domain analysis

This section is used to sum up and explain what important information can be drawn from the work domain analysis. This material is solely an interpretation by the author.

From the information of functions gathered from the AH (in the middle level), some of the functions can be identified as essential for the supporting of the abstract function level. The functions most important for the systems operability is the functions of identification, spotting of new tracks, tracking, interpreting the tactical situation and exchanging information. These

functions are also made up of many components (see “Appendix IV: Complete AH”) that needs to be available for the system to be fully operational.

From the AH it is clear that the C2STRIC is not the only tool used for air surveillance, there are several tools and functions used in the work. One example of this was showed with the identification process. Several tools are used and several abstract functions must be met.

## **5.2 Control task analysis (ConTA)**

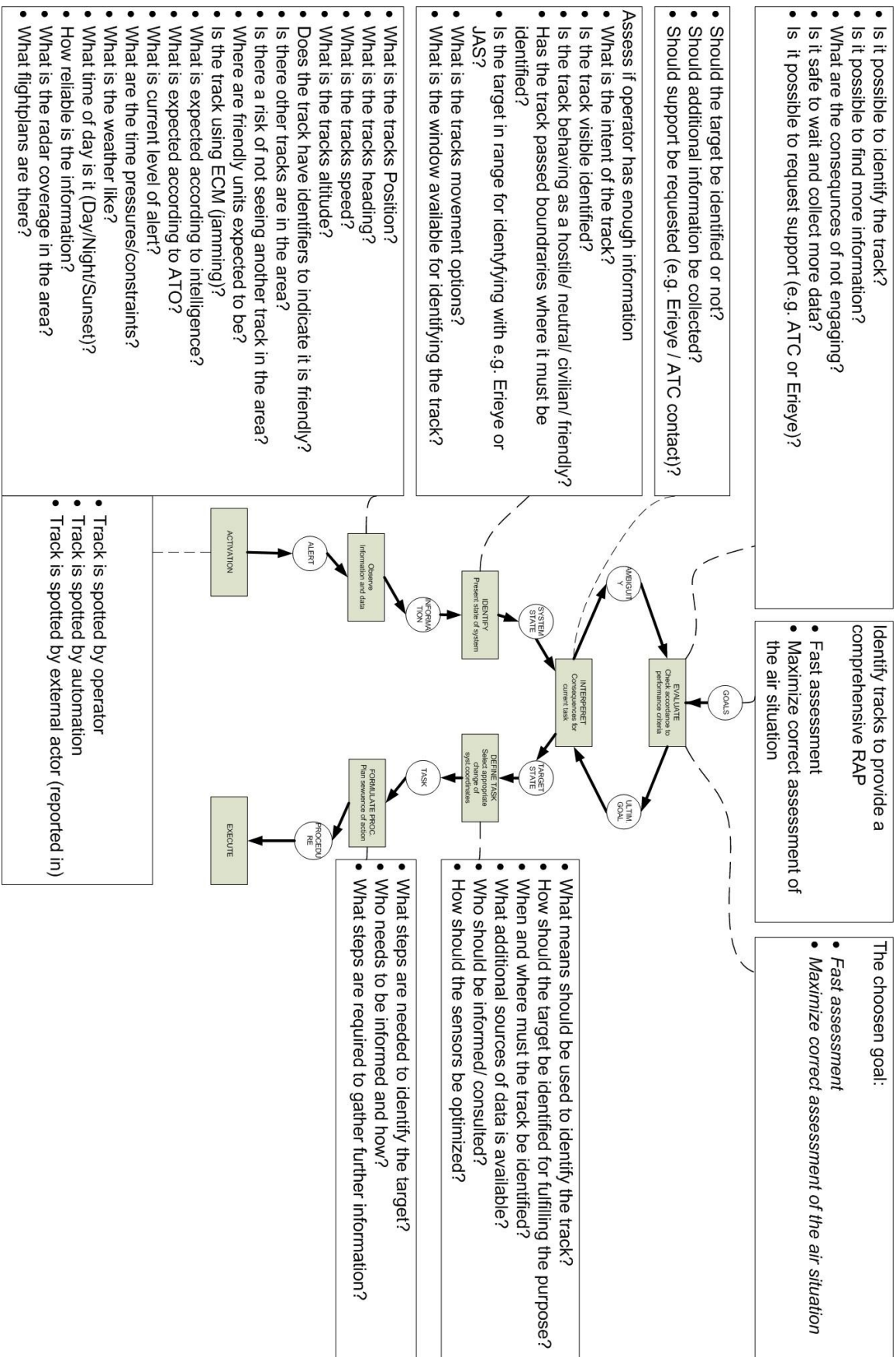
The control task analysis is, as was explained in chapter 4: Method, based on decision ladders. First a generic decision ladder is shown to illustrate all possible options available to an operator when identifying a track. After the generic ladder, some more specific ladders are presented for the identification process. Lastly a generic DL for optimization of radar stations is presented.

### ***5.2.1 Decision Ladders of the identification function***

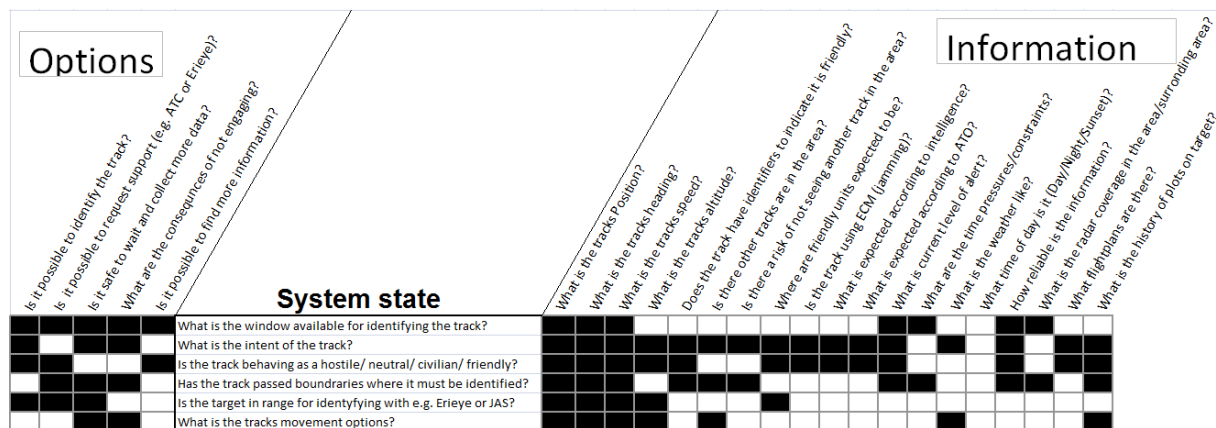
#### ***5.2.1.1 Generic decision ladder of the identification process***

The cognitive processes when making a decision shown of a track can vary depending on situation and decision. The identification process is shown in Figure 21. Not all shortcuts is recorded in this figure, instead all possible information about decision states is recorded.





It is important to see the links among different elements in this generic decision ladder, for this representation is seen in Figure 22. In the middle different system states can be identified, to the left in the figure, the options for actions is presented and to the right is a representation of what information is needed.



**Figure 22 links between states in the decision ladder**

These two ladders are a good start when finding all possible options. To show more specific cases decision ladders with more specific scenarios is used.

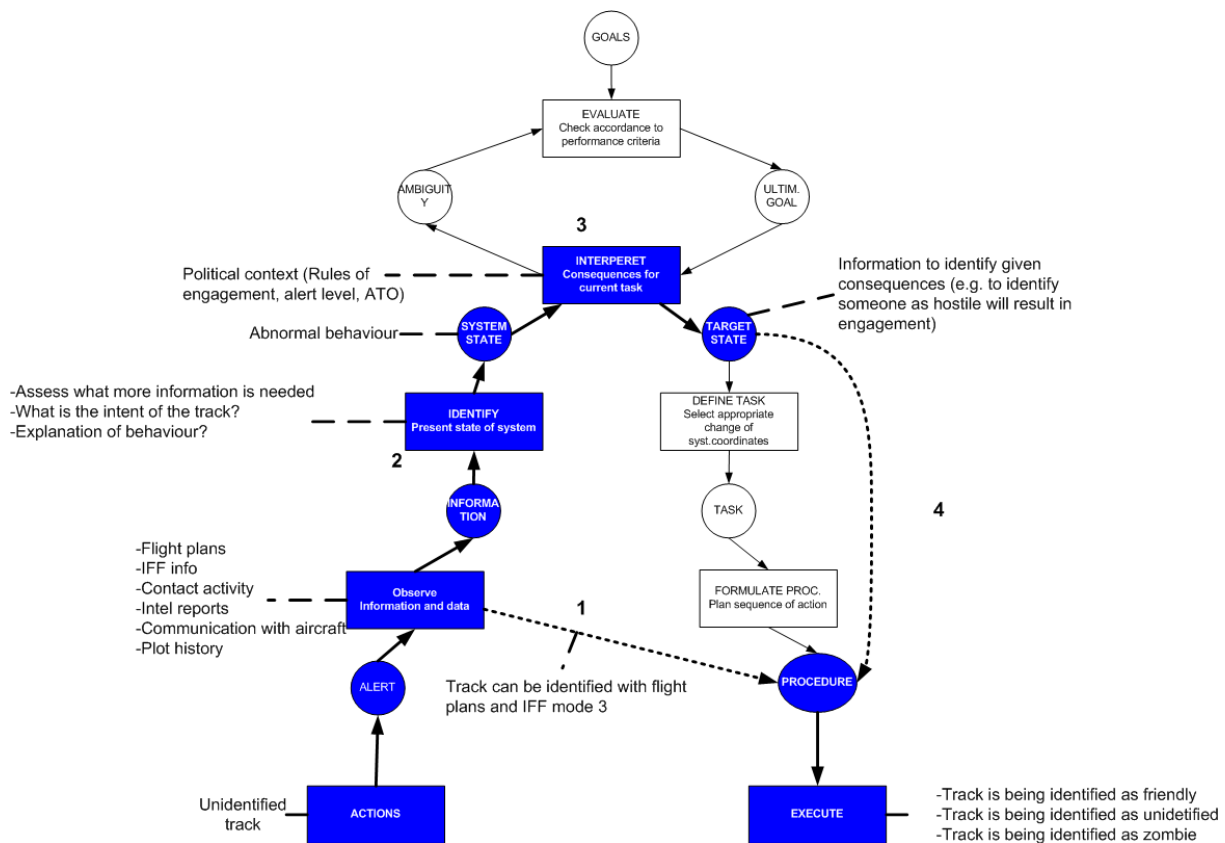
In Figure 22 we can see system states of the decision ladder in the middle column, the information needed to reach the system states in the right column and lastly the options available (corresponding to the ambiguity state of the DL). An example using one of the system states is used to explain the links; “*Has the track passed boundaries where it must be identified?*” information needed to answer that question and reach the knowledge state are;

*“What is the tracks’ Position? What is the tracks’ heading? What is the tracks speed? Does the track have identifiers to indicate it is friendly? Is there other tracks are in the area? Is there a risk of not seeing another track in the area? What is current level of alert? What are the time pressures/constraints? How reliable is the information? What is the radar coverage in the area/surrounding area? And what is the history of plots on target?”*

And the options available in this state are; *what are the consequences of not engaging? Is it safe to wait and collect more data? Is it possible to request support (e.g. ATC or Erieye)?*

#### 5.2.1.2 DL of a track following air traffic rules, but has abnormal history

In Figure 23 a decision ladder describing what happens if a track is heading for Swedish borders and follows the pattern of a normal traffic jet and matches a flight plan. In this first scenario a skilled operator can easily and without much cognitive effort tie the flight plan to the flight and set a friendly identity (see connection 1 in Figure 23).

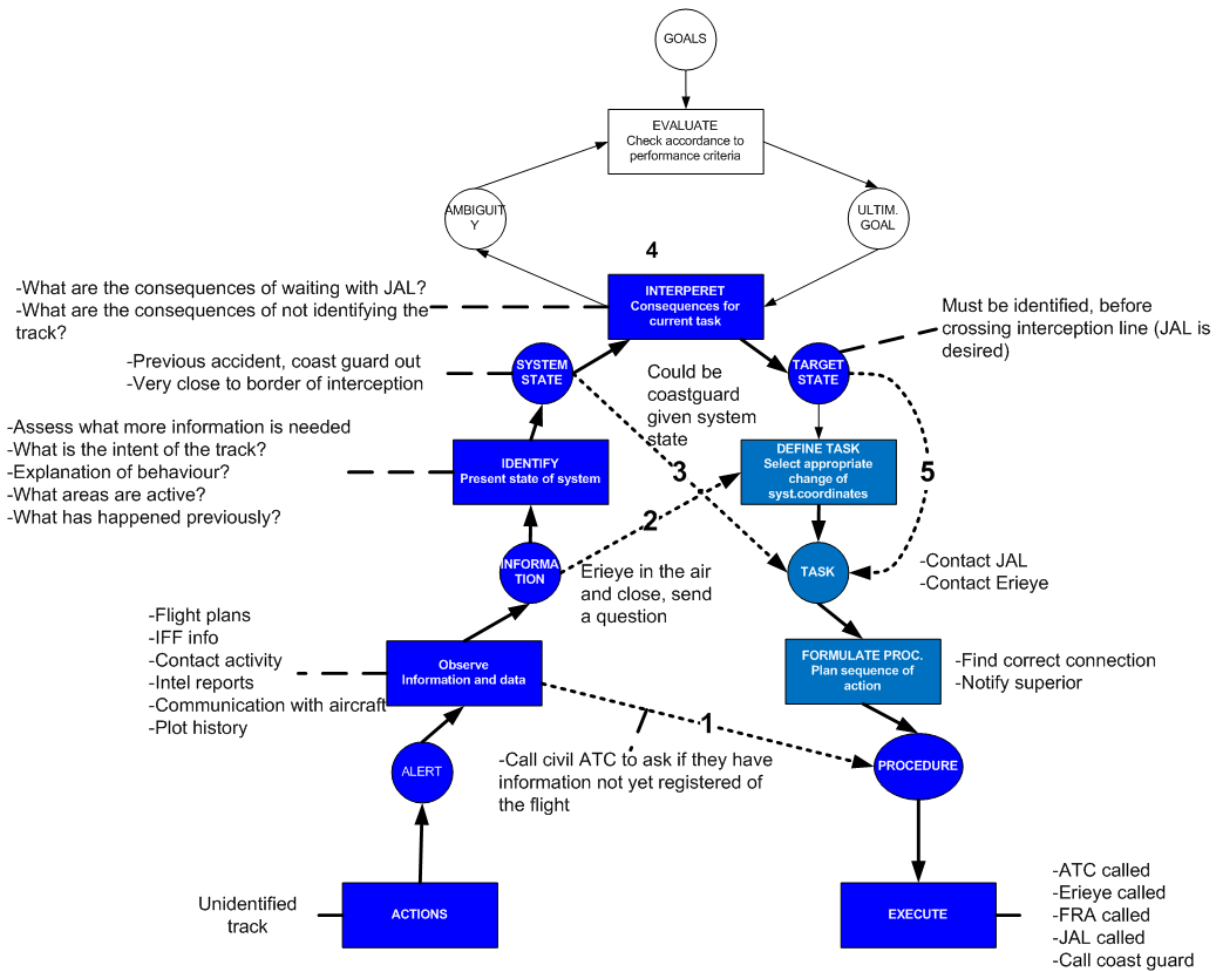


**Figure 23** Decision ladder of detection of a track that follows the same patterns as civil traffic aircraft, but has abnormal history.

If the operator however sees the abnormal plot history where the plan has made several sharp turns, further evaluation of the information takes place (2). A hostile usually never has enough information on them, but indication of turns can help come to the conclusion that the current state of the aircraft is behaving suspect. To identify the system state (2) can be done by seeing if they are using electronic counter measure not to be seen, there is no ongoing exercise and the political context (3) is not at a heightened alert level due to hostile context, the operator knows what consequences their action of identifying the track as a zombie (appear to follow civil traffic pattern) or unknown (no information of identity) and in connection (4) goes down to the knowledge state where a pre-planned procedure takes place.

### 5.2.1.3 DL of a unidentified track without a flight plan

Another decision ladder is shown in Figure 24 and describes how the decision of who to contact for a correct identification of the track.

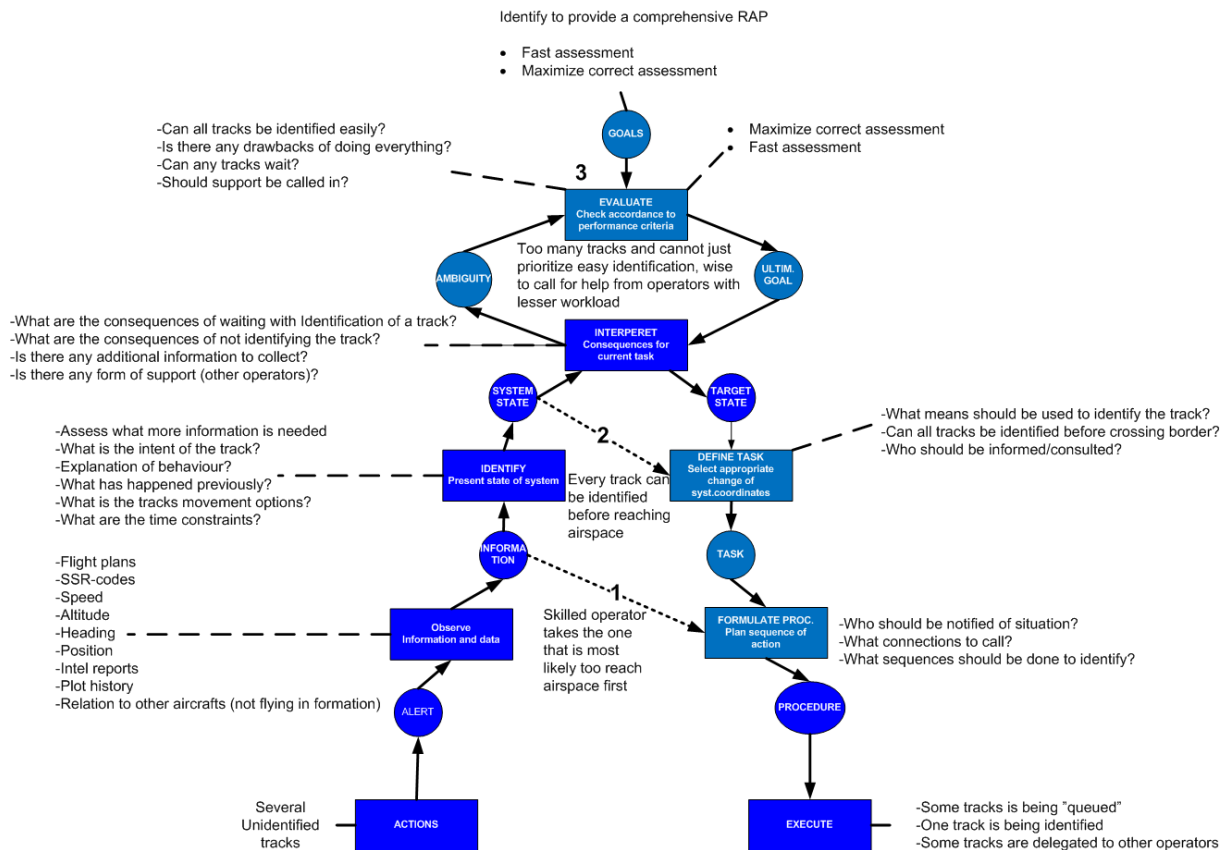


**Figure 24 Identification of an unknown track without flight plan.**

If a track is approaching Swedish borders without flight plan some basic steps are made. In the observe step SSR and database systems are searched. If the plane has an IFF-code but no flight plan in the system, the operator quickly decides what the next step should be (connection 1). If the plan however have no IFF-code and no other information, and the operator knows that they have an Erieye in the area with ESM capabilities, the operator can decide to contact them for more information (2). If there is time and the behaviour of the track resembles a coast guard surveillance plan that corresponds with reports of previous accident, the operator knows what task to accomplish (3 –contact Erieye). If the plane is close to the border and the operator at (4) realizes that consequences of not identifying with JAL is in direct conflict with the goal of identifying everything passing over the Swedish airspace borders, the operator knows what task to conduct (5 –contact JAL).

#### 5.2.1.4 DL when several tracks are unidentified in a operators surveillance sector

The next DL show a decision process set in the context where one operator has several tracks to process. Usually the operators can handle the situation, although sometimes extra help is needed.

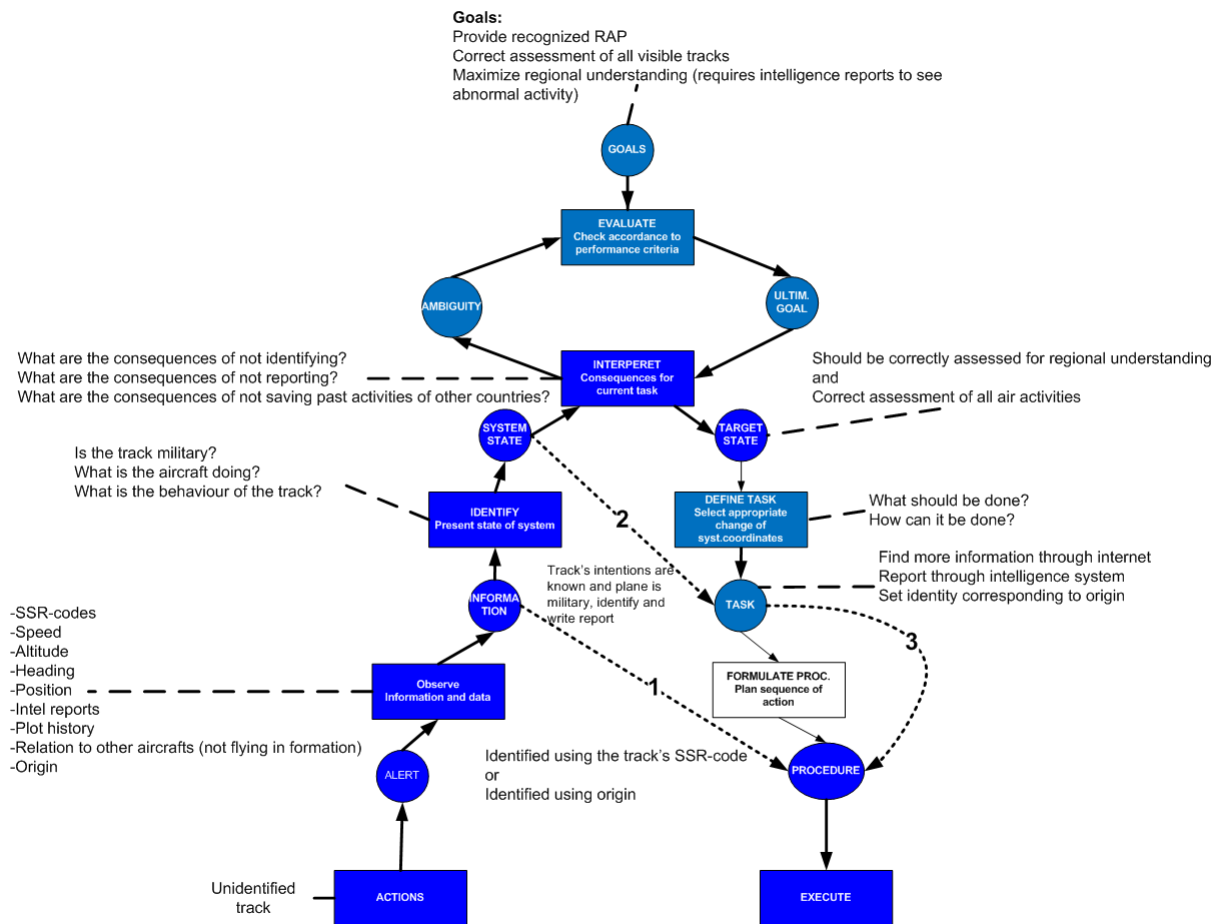


**Figure 25 the decision process when there are several tracks to identify**

When the workload increases and an operator has several unidentified tracks heading for Swedish airspace, another decision process first takes place, in this situation three ways of making the decision has been found. First of all information of tracks are identified, a skilled operator can sometimes immediately go from information to formulate a procedure to identify a track (1), this evaluation is done on the basis of the track's altitude and speed, a low flying track is prioritized in front of tracks flying on traffic height. An operator can also go all the way up to indentifying the system state and if the operator feel that everything is under control, can identify all tracks by building up a "queue" and process the tracks one by one (2). If, however, there are tracks closing in fast and the operator cannot satisfy both the correct assessment and fast assessment demands (3), an evaluation of other options for identification is made and if there are operators with lesser workload, some of the responsibilities can be delegated and the operator can thus start identifying a decreased number of aircrafts.

#### 5.2.1.5 DL of the identification process when a track is not affecting Swedish airspace

Tracks not affecting and are not likely to affect Swedish airspace is classified for understanding what is going on in airspace close to Sweden. The following DL describes the decision process in that context.



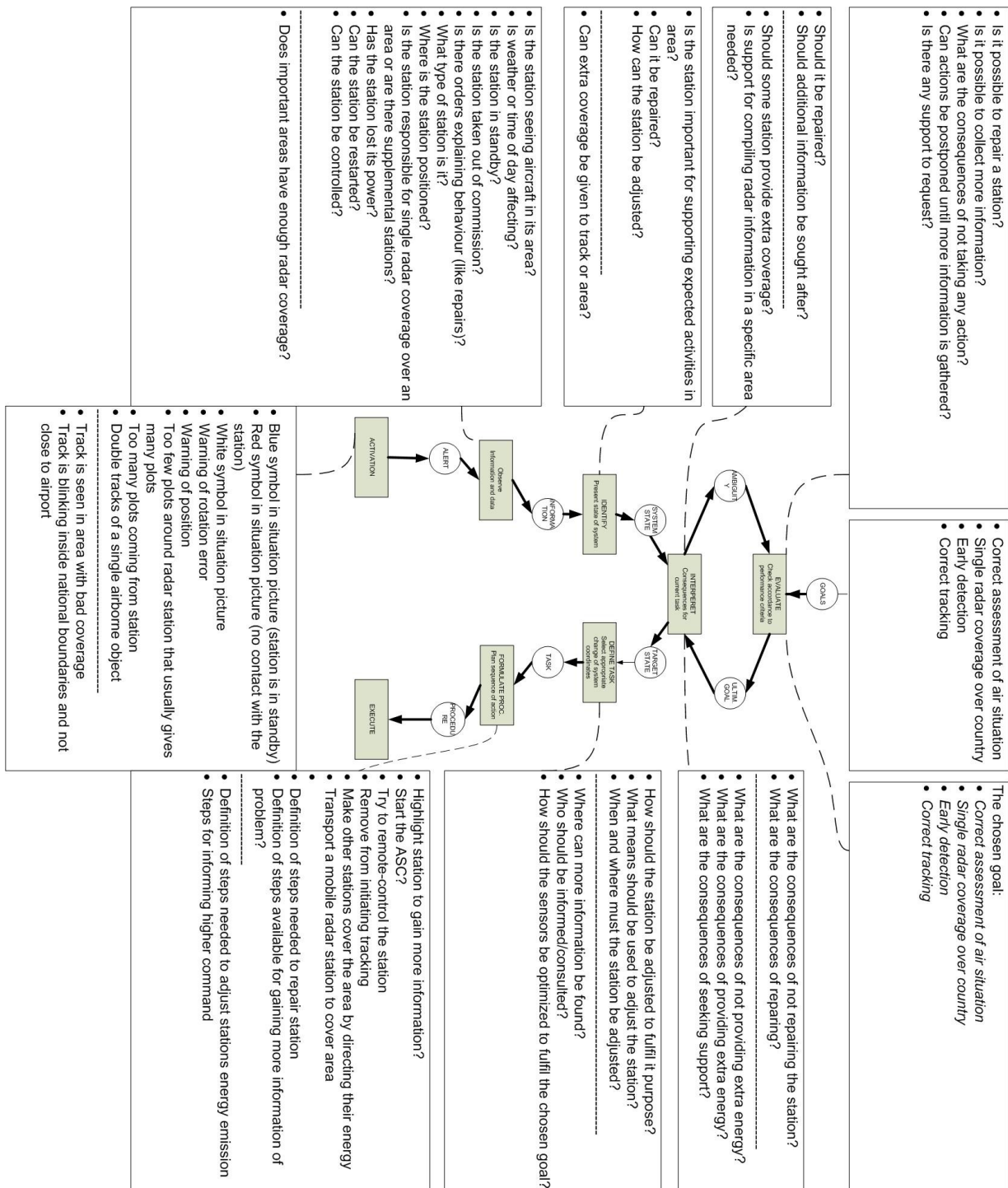
**Figure 26 Identification of an aircraft outside and not affecting Swedish airspace**

A track not heading for Swedish airspace, but is spotted by sensors are also a subject for identification process. The easiest way of this identification is when the tracks originates from a military airport or have an IFF-code known to foreign military (1). Another case is when information is missing but behaviour resembles for example a foreign flying radar, the instance is reported to intelligence and aircraft is identified (2), there is no planning this simple procedure since it is done so many times every shift, the operator knows what to do (3). If there is a lack of information and identification becomes harder, other evaluations are made. The decision process can then reach all the way to the top where it may be considered that it is important to at least come up with some idea of what is travelling abroad. This identification can require more work and for example one way of defining the task can be to go out on the internet to search for information of foreign exercises.

### 5.2.2 Generic Decision Ladder of the optimization of radar stations

The other generic decision ladder created consisted of the optimization process of radar stations shown in Figure 27. This optimization was described in the AH for air surveillance, the optimization of other equipment is not a part of this figure. The information boxes are the same as the boxes in Figure 21 (the generic DL for the identification process), although they of course have a different content. This decision ladder is used to illustrate how another generic decision ladder can be used. As stated earlier in the method chapter, the detailed ladders of the identification process will not be shown for this decision ladder. This ladder is merely used to show differences.





**Figure 27 Optimization of radar stations; a generic version of the decision ladder with as much information as possible for each step when processing information**

It is relatively easy to understand the differences between the two generic decision ladders, the previous one is for identification and Figure 27 is used for optimization of radar stations. The main goal of the optimization process is to make sure proper coverage is implemented throughout the entire airspace. The decision ladder will not be explained in detail. The ladder is merely shown to illustrate a different context of the generic decision ladder.

### **5.2.3 Summary of the ConTA**

The generic decision ladders allows for easy overview of what information must be available. The information should be easy to find and should be available at all times when identification process is undertaken. This should be supported by the C2STRIC system; the operator should not have to move their eyes to much over the screens to locate all the information needed. Deciding where the interception line is can be hard; it depends on speed, heading and location.

The more specific decision ladders show that the more experienced operator can take several shortcuts. Designing a system for these behaviours are important, as well as designing the system for the full chain of decision ladders. The context of decision ladders were chosen of the amount of information gained. All possible contexts that are used cannot be predicted by an analysis, which is why the generic decision ladders provide an important factor for when trying to see all possible relationships.

## **5.3 Strategies Analysis (SA)**

### **5.3.1 Information flow map**

The overview in Figure 28 does not describe exactly what happens within the system, this figure describes how work is carried out within the system. The figure should not be mistaken for the abstraction hierarchy, the information flow map can have several different layouts and this one is chosen for its ability to present information without making the flow map too complicated and disorderly. The overview in Figure 28 gives a basic explanation of how different tasks and situations where tasks are carried out. Since the picture is large and an important overview of work within the domain, a comprehensive walkthrough is used to inform the reader of strategies used in the air surveillance work. The representation is made for work in peacetime and after the system is up and running.



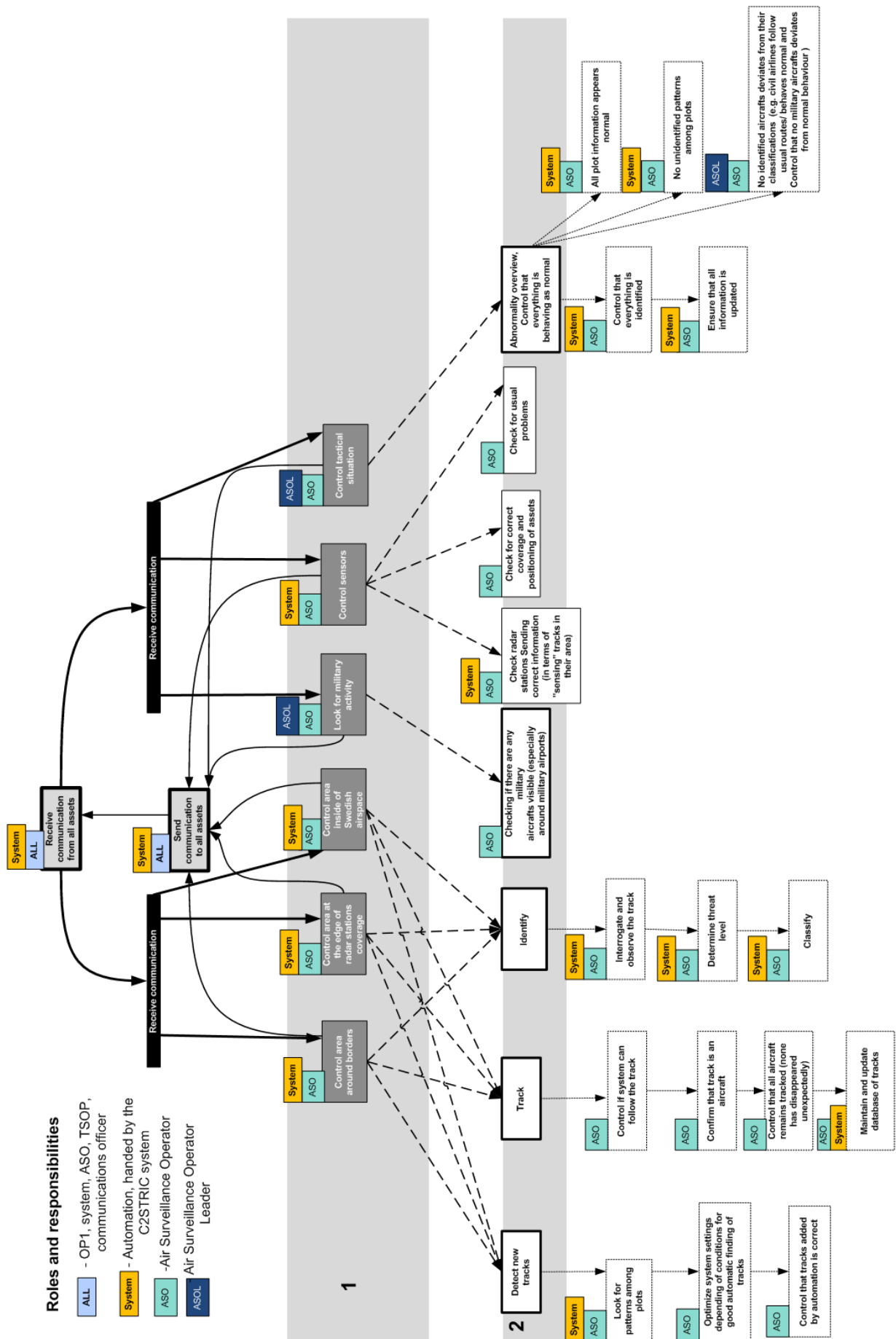


Figure 28 an overview of strategies used to describe what occurs within the system

At the middle level (1), the main categories of how an operator moves their focus on different parts of the system has been placed. Several operators referred to these functions as the surveillance cycle. This cycle can differ among operators and it should be clear that this figure is a generic overview and the focus can move randomly between the boxes and very different intensities (sometimes only focus on one box once every hour), it is not tied to a specific operator. In the first box of level 1 is the strategies of checking around own airspace borders and this is an important step for air surveillance operators. They have to control what is heading for borders, track everything and make sure that nothing passes the borders unprocessed (it is not the work of air surveillance operators to stop aircrafts from passing unidentified, their work is to notify the JAL that something unidentified is heading for airspace). This task is both done by the system and the operator 1.

In the second phase of the strategy, an operator observes what is going on far away from Swedish airspace to start processing early; this is also done to predict what will affect Swedish airspace later on. The tasks of early spotting, tracking, identifying is made by both the system and operator 1. Whereas the mental picture of the future is solely done by the operator 1.

Box three represents the task of surveillance everything inside Swedish airspace, this means traffic flights as well as identifying all starting aircrafts. This step is also made to create a mental picture of what the RAP will look like in the future. Creating the prediction of future state is done by the operator, with the other three steps linked to on the level below (level 2), the system helps.

The fourth step is to look for military activity in any form and this is done by (e.g. looking around known military airports, scan for known IFF-codes, observe behaviour). This information is important aspect to send in intelligence reports and this qualitative data is collected by both OP1 and the ASO.

The fifth box on level 2 (see Figure 28) corresponds to the task of controlling the sensors of the system. It is important (even if there is no alarm) to control proper functioning of the sensors. This function is done by both the system and OP1.

The last box in level two symbolizes the strategy where the tactical situation is controlled. In this step abnormalities and a “complete” overlook is made to determine what the systems status is. This is done by the system, ASO leader and OP1 (ASO).

All these middle strategies, exchanges communication with other resources and this function is not in the focus of this thesis due to delimitations made on the abstraction hierarchy and task analysis. It is however worth noticing that exchanging information is a big and complicated area. For example a network must be set up and maintained, filtration of information must be handled and coordination of resources is parts of this functionality. This exchange is handled by the system, the OP1, the ASO and also the operator responsible for communications.

Level 2 (see number to the left in Figure 28) consist of several tasks that all fits inside the general boxes on level 1. All boxes should be explained for the reader to understand how the surveillance cycle works. First of all detection of new tracks is based on looking for new patterns among the plots on the map, this is done by both the system an OP1. Detection of tracks also involves setting

the automatic system for correct finding of patterns (this is done by changes in the MST). Sometimes the automation sees tracks that is not really an aircraft (could be birds), resulting in false tracks that the operator have to filter out manually.

The second box is tracking, this is done by controlling that the system can follow the track without losing quality of the information, the track should not be lost. In this function the track is evaluated again to confirm that it actually represents an aircraft, this is done to avoid realistic echoes that does not represent an aircraft but appears to not be moving (due to the fact that the track is put on for example a weather phenomena). Another function is to make sure that no tracks have suddenly disappeared without any apparent reason, this could indicate for example indicates a crash. The system should store information of past positions and continuously update all track information, updating can be done manually by an operator if the track for example is outside the settings in the MST.

Identification of tracks consists of interrogation (using sensors to find as much information as possible, including asking with SSR-radars), determine what abilities the aircrafts have (to use as base when classifying) and lastly classify the track.

Another task down at level 2 is to look for military aircrafts; this is done to support surveillance reports, keeping control of threatening activities, reminder for the operator to look specifically at military activity.

The next three tasks are all concerned with controlling radar stations functionality.

The last category of tasks in level 2 is concerned with checking for abnormalities. The term abnormalities refer to unusual behaviour. It includes looking for strange plot formations (perhaps indicating bad weather); look for unusual patterns among plots that can indicate something has been missed. Another big point in this section is to control that all aircrafts are behaving as normal (e.g. traffic jets follow their flight plans, assumed civil within Swedish borders are not allowed to go out and come back into Swedish airspace and aircrafts with special permissions does not deviate from them). This step also includes an overview to make sure no aircrafts are unidentified, also looking for error messages indicating that the system is not updating all information.

### ***5.3.2 Identification strategy flow map***

The overview in Figure 28 is an important representation of the work within the system, although the representation does not show any links between the processes in level 2. To show links between tasks and strategies Figure 29 is used. The links is important to show how an aircraft can enter the system on the basis of only sensors and show up identified on the RAP.



The top box denoted “A. Work allocation” is not directly linked to the steps below, although they influence and affects all different steps below. Allocation of airspace is an important step affecting strategies used and in what context the work takes place. This is explained further in section 5.4 (Social, Organizational and Cooperation Analysis).

Starting in the upper left corner of Figure 29 (1) the track enters the system, and three types of strategies can be used to find a track (see figure). The track is then followed in the tracking process (2) where three types of tracking can occur. It should be noted that the tracking process never ends, it continues throughout the entire lifecycle, the tracking process is illustrated as a box to show that after proper tracking is enabled other functions occurs. In the figure there are three types of strategies that can be used to add a track (e.g. if a track is added by automation the operator can choose to reject, accept or correlate the track with existing tracks). The next step is to optimize sensors for correct following of the track (3). And this can be done by three types of strategies depending on the situation. One of the strategies to the left where operators try to repair the stations, they will have to take the external right to manoeuvre the station. Only one central at a time can manoeuvre a station. There are some rules of who can and when an operator can gain stations manoeuvrability. To ask for manoeuvrability within the system, the operators have to check in a box in a radar definition window. If the stations problem can be resolved the track enters the identification process. To recap; after the track is spotted, tracked and properly “sensed”, the identification process begins (4\*). There are three main ways of identification that changes depending on the situation. If the track is affecting Swedish airspace (4A & 4B) certain strategies occurs, this can be compared to the situation of the track not affecting Swedish airspace (4C).

In the situation (4A) when a track is heading for Swedish airspace, typically the first thing that occurs is an interrogation with IFF mode 3 where an IFF-code is received. If the aircraft fail to provide a correct SSR- code, the right chain of strategies takes place where identification takes place with calling external resources for more information and contacting resources to identify the aircraft with visual means. If, however there is an IFF-code the left side of the chain is activated. In the left chain the operator tries to find a correct flight plan and connect it to the IFF-code. If an aircraft cannot be connected to a flight plan or it has a flight plan but also an unusual behaviour, other means of identification is needed. There are several different ways to resolve identification in that type of situation and it is usually a problem-solving work involving several sources of information that takes place, one of the sources s to visually identify the aircraft through fighters.

In a situation where a track starts inside Swedish airspace (4B), there are some special rules that can applies; a track starting inside Swedish airspace doesn't have to have an IFF-code or flight plan. If these two factors are missing, the plane is not allowed to leave Swedish airspace and not fly into protected air around airports (if they are missing transponder with IFF-code the civil ATC can't see them).

In a situation (4C) when a track is travelling outside Swedish airspace and is not close or heading for the airspace, some basic steps occurs, the first thing assessed is whether or not the aircraft is military. Non military flights are not interesting in this situation. A military aircraft on the other hand is identified according to rules about who they are associated with.

When identities and good tracking are set, the aircraft enters box number 5. Here the goals of the system are presented, and they are to correctly follow and identify the tracks, together with effective sending and receiving of information within the system.

The last of the strategies is to interpret the tactical situation (6). This can be done by making sure that the identification goals of the system are correct. All identified aircraft should have behaviour corresponding to their flight plans and not make sudden changes in their behaviour.

### 5.3.3 Identification strategy diagram

Figure 30 is used to recap in a summarized fashion to show that there are different ways for a worker to identify an aircraft, much of the work within the system is based on the cooperation of aircrafts, in a war situation cooperation of aircrafts are likely to vanish. The system expects the aircraft to give information about who they are when interrogated by the SSR radars. The drawbacks of this interrogation identification system are the fact that friendly aircrafts, failing to cooperate will be classified as hostiles or enemy forces can trick the system and thereby mask their activity. Cooperation of aircrafts means that they give information of who they are by sending their transponder code which can be linked to their flight plans, although some aircrafts are harder to identify and other sources like internet and civilian air traffic controllers are needed, the last resort is to contact JAL (fighter leader) who have the authority to send two Griffins (JAS 39) to visually identify the aircraft.

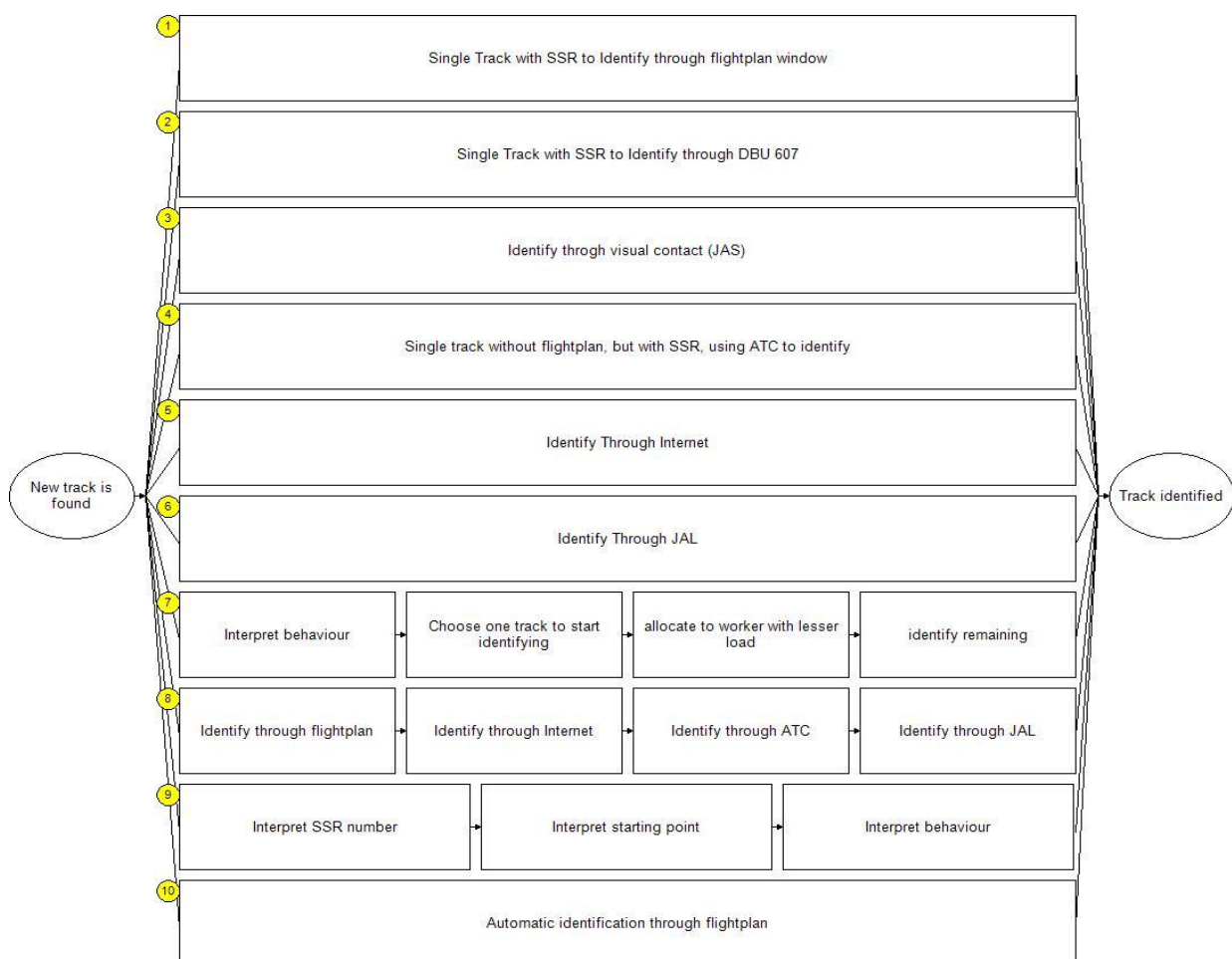


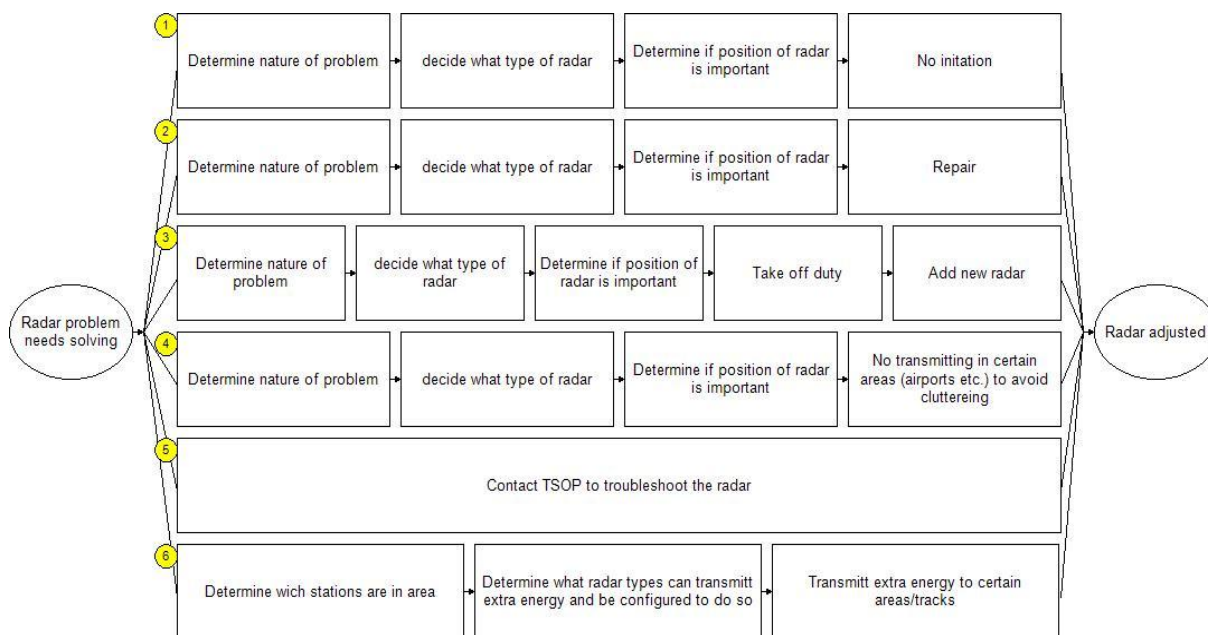
Figure 30 Identification diagram simplifying identification process

When a track is found, the identification process starts. Identification can be done by; (1) connecting the aircrafts transponder code (received from the SSR) and linking this to a corresponding flight plan. When aircrafts is harder to identify (no transponder code available, or no flight plans connected to the transponder code) other ways of identification is needed. (2) If the plane is on its way in to Swedish territory, a rote (two fighters flying in tight formation) is sent up to identify the plane visually. (3) If the plane has a transponder code but no flight plan, and the plane is not considered to show any unusual behaviour, the operator calls a civilian ATC to get the missing flight plan. (4) If multiple unidentified planes enter a single operators area of responsibility, an aircrafts behaviour is interpreted (if it's flying fast, low, heading for restricted areas, etc.) to determine who has priority. The most important is the first identified and, if available, allocates the other aircrafts to operators with a lesser workload. When the first is identified, the loop starts over until all tracks are identified. (5) If there is no flight plan in the system, the operator can go online and check the transponder code for the plane against all flight plans in Europe. If there is none, the operator can call a ATC (they hold all flight plans in Swedish airspace and sometimes forgets to send changes in flight plans), if they have no information the identification of the aircraft is done by JAL sending a rote up to visually identify the aircraft. (6) If the aircraft is not heading for and the range is far away, the plane can often be identified loosely by interpreting the transponder code (some aircrafts always has the same prefixes), the operator can track the planes start location and determine if it is a friendly nation/ civilian airport and by interpreting behaviour such as speed, number of turns, type of turns and in which airspace areas they are operating. (7) There is also an automatic identification, this function automatically associates aircrafts with the corresponding flight plan (if an aircraft turns up at the right location in the right time with a transponder code matching corresponding flight plan) and sets the identity.

#### ***5.3.4 Optimization of radar stations strategy diagram***

A strategy diagram was created for further illustrating what strategies can occur when a radar station needs to be optimized. This diagram shows a summary and is only used to give basic information of the strategies used to optimize radar stations.





**Figure 31 A strategy diagrams showing the most important strategies when adjusting radar**

In Figure 31 six strategies are presented, the first four strategies have the same actions and only differ in the end stages. Using the strategy diagram we can easily see what differs from the strategies and this allows for the interface to be adapted to the use. Strategy number five is often used when operators have no time to control what is wrong with a station, or the stations shows an previous error that usually the TSOP can solve. The last strategy (6) is not concerned with troubleshooting of radar stations; this strategy is used when configuring the energy of radar stations for extra focus on interesting activities or areas.

### 5.3.5 Summary of the strategies analysis

The different steps in the surveillance cycle could have more support by the system. Functions designed specifically for each step in the cycle would help operators.

When observing the information flow map from the identification process (Figure 29) it is clear that several of the boxes are very big and needs to be investigated for understanding of how the activity occurs in the system (e.g. the box in square A in Figure 29, contains a small post representing the task of dividing airspace, dividing airspace among two centrals requires a lot of communication and common references, first of all a no accept zone is set up and then two fake tracks are created as reference points and then a detection area is drawn between the fake tracks, lastly several settings is made to accept tracks from other centrals).

The information flow maps shows what is needed when identification of a track should be carried out; who executes the process is not specified. This information could especially help decisions of categories when toolbars and shortcuts are implemented.

## 5.4 Social, Organizational and Cooperation Analysis (SOCA)

The roles and tasks to be accomplished by STRIL are governed by the TOEM STRIL battalion; this document is in the parts concerning air operations is partly based on the Swedish doctrine for air operations (Nordin, 2009). The TOEM governing the work of the STRIL battalion is however

confidential and the specifics of the work allocation and coordination is not available for non-military personnel without a certain grade of security clearance.

#### **5.4.1 Roles within the air surveillance function**

There are some facts concerning work that does not require security clearance. For instance, there are a few different roles working with air surveillance and there is a difference during war and peace. During peacetime there are only three multi role officers (MROs) covering Swedish airspace and an air surveillance leader, the communications is handled by the communication officer and technical system is managed by the technical support operator. When operators surveillance the airspace, there are specific sectors that each of the MROs cover and the air surveillance leader is the coordinator and controls all actions within the system is correct.

Information about war time is to some extent confidential, what is clear is that during war time, several other roles will be used to handle the system (e.g. a radar officer, radio officer, master tracker etc.)

The responsibilities of the personnel within the system are presented through all figures with small annotations for easy representation of what different persons within the system do. The different roles within the system are; Communication officer (COMOFF), Head of Radio (Raled), Radar officer (RadarC), Multi role officer (MRO), Master tracker 1 (MT1), Air surveillance leader (LBEV), Air surveillance operator (ASO), Fighter leader (JAL), Head of Radar (RADARC) and Technical Support Operator (TSOP).

#### **5.4.2 Communication**

There are a few standard situations when an operator within the system must contact and communicate with operators around them;

##### **An operator always notifies the air surveillance officer if:**

- A violation of Swedish airspace is anticipated
- An unknown company or flight activity without permission is close to Swedish airspace.
- Foreign military air operations
- Foreign air transports of heads of state and government with permission to enter Swedish airspace
- Delimitations of sensors, system, etc.
- Anything deviating from the normal state or anything that may be of interest.

##### **Communication between operators is used to:**

- Allocate working sections
- Determine workload of other operators
- Troubleshoot the system
- Switch operators
- Switch operating central

### **Communication to TSOP is used to notify if:**

- Error in sensors, system, etc

### **Communication with JAL is used to notify if:**

- An unidentified aircraft is close to Swedish territory

#### **5.4.3 Work allocation**

The work in the system can be allocated in two main ways. These two are shown in box (A) in Figure 29. The two ways are to allocate responsibilities within the air surveillance work is to allocate responsibilities within only one central responsible for the whole airspace and the other way is using the Link 16 network and allocate the airspace to different centrals with areas of responsibility. Allocating among different centrals puts high demands on communication devices for contacting other operators and control work.

#### **5.4.4 Summary of SOCA**

It must be noted that the box (A) in Figure 29 only is a very coarse overview; it can for example be expanded with processes of handing over the whole RAP, receiving the whole RAP, differences working with other countries and differences between war and peace.

When working over the link 16 network, the allocation of work and division of airspace is likely to be with shared areas of responsibilities between centrals. For a Compact C2 system with a lot of focus on international compatibility this factor is very important to investigate further. Especially how communication happens over the network, how the identities change, can an operator take over track and change identities on another station's tracks are important questions to study.

In the cases where the automation does not work to share the responsibility and operators must be used to manually take responsibility over the tracks, an extra operator could be used. When an MRO works with the task of handing over and receiving tracks it takes a big amount of focus and the task is very time-consuming, this affects the completion of more important tasks.

Handing over the responsibility of a complete RAP to another station is also an important part of the cooperation. The handover process stands much to gain from an easier way of sending and receiving the RAP, at the moment there are several settings and filters to turn on and off.

Also the cooperation tools when working with other centrals should be evaluated. Currently the centrals used fake tracks to communicate points, otherwise geographical reference points are used. One common way to show exact position between centrals is making the cursor appear on the screen the operators are talking to. If however international cooperation is undertaken, geographical names can differ, fake tracks can be misinterpreted by other centrals not listening to the communication of the two centrals coordinating their areas of responsibilities and the cursor showing will not work.

The communication patterns between operators and air surveillance leaders can be helped by a notification system in the system where a track, breaking one or several of the rules listed earlier, receives a special marking (e.g. a blinking cross). Instead of calling the technical operator, the system could provide help with the contact.

## 5.5 Worker Competencies Analysis (WCA)

When an operator takes over on his shift, he should have some basic information about radar stations. This information is what type of stations are online, which are offline (prognosis, expected time ready to use), planned interruptions, warnings (if lightning, storm, wind), and other disturbances.









### 5.5.1 Operator Training

Training of the STRIL-battalion is carried out by LSS (“air combat academy”) located at F20 in Uppsala. To train for air space monitor is a three year education and the same for air combat leaders. There are two different ways to become an air surveillance operator, one is to undergo the three year officer program and the other is a one and a half year training to become a system specialist.

The education of Swedish tactical air surveillance’s is six semesters (three years). The training starts with a basis for Swedish officers with three semesters of political knowledge, tactics, defence branch knowledge, military technology, leadership and physical fighting value. Semester four and five are focused on the more specific training for the positions and functional training. Here the personnel are trained for job duties in the system C2STRIC and meet experienced air situation watchers. During the training, theory is mixed with practice and a great deal of time is spent in the simulators (C2STRICS). The last semester is used for writing a bachelor thesis. (Försvarsmakten.se)

### 5.5.2 Skills, Rules & Knowledge taxonomy for track handling

A WCA table for target acquisition is shown below in Figure 32. It is inspired by the strategies shown in Figure 29; a track is found, investigated, evaluated and then identified.









Finding track to identify	Information processing step	Resultant state of knowledge	Skill-Based Behaviour	Rule-Based Behaviour	Knowledge-Based Behaviour
<b>1</b>  Activation > Alert	Searching for new tracks	New track is confirmed	Monitor all airspace for change	Anticipate where a target will be found based on wether and time of the day	Interlikely positions
<b>2</b>  Observe > Set Of Observations	Determine type and location of the new track	Understanding of capabilities and location of the track	Direct observations made on the track	Experince used to draw conclusions of capabilities based on visual cues	
<b>3</b>  Identify > System State	Calculate threat of target	Understanding of implications and the targets capabilities / location	Simple conversion of capabilities to threat	Experince used to draw conclusions on the threat level based on target location and capabilities	Target threat considered against overall objective
<b>4</b>  Interpret > Ambiguity	Calculate if track is a priority	Understanding of the tracks priority	Priority based on a single factor (i.e. track location is outside Swedish airspace vicinity)	Simple balance applied to decide priority of targets (this is done by using experince)	Targets prioritised by referring to the overall objectives and implications
<b>5</b>  Evaluate > Ultimate Goal	Evaluate implications of not identifying the track	Understanding the effects of not identifying the target	Consider implications based on correct understanding of information	Consider implications based on previous implications	consider implications by hypothesing possible implications
<b>6</b>  Interpret > Goal State	Determine if target needs to be identified	Wheteher or not target should be identified	Protocol used to decide if the target should be identified	Protocol used along with exceptions statements collected by experince to conclude if target should be idetified	Deviations from protocol considered against overall objective
<b>7</b>  Define Task > Task	Assinging the correct method (Operator and flightplans   JAL   ATC   Internet )	Effecter assigned to target	Assign target based on single factor (i.e. Workload / JAL is busy with other duties or Location - JAL cannot identify outside swedish airspace)	Using simple rules to balance the workload	Assigning based on the greatest effect on overall system purpose
<b>8</b>  Formulate Procedure > Procedure	Determine which track to identify	Track Selected	Track selected in priority order	Tracks are selected in priority order unless new information is gained	Tracks are selected based on greatest effect on overall system purpose

**Figure 32; SRK taxonomy for identification Swedish military air surveillance**

The description of how a track is identified is not connected to a specific case, but takes into account that an operator has to evaluate threat when for example a prioritization is made of which track to identify.

### 5.5.3 Skills, Rules & Knowledge taxonomy for optimizing radar stations

Another SRK-taxonomy describing the optimization of radar stations is shown below in Figure 33. The optimization of radar stations is based on several steps and this is one way of representing the work needed and behaviour of the worker to optimize the radar stations.

Optimization of radar stations	Information processing step	Resultant state of knowledge	Skill-Based Behaviour	Rule-Based Behaviour	Knowledge-Based Behaviour
1  Activation > Alert	Searching for erroneous radar stations	A faulty station is confirmed	Monitor plots for changes	Wait for station to become red in program or select station within a interval to see if station is still working	Likely stations to malfunction
2  Observe > Set Of Observations	Determine type and location of radar	Understanding of the radar station's capabilities and location	Direct observations made on the radar station	Experience used to draw conclusions based on location	
3  Identify > System State	Calculate importance of the station	Understanding of implications and the targets capabilities and location	Simple conversion of capabilities to importance	Experience used to draw conclusions of importance based on station's location and it's capabilities	The importance is considered based on the overall objective
4  Interpret > Ambiguity	Determine if radar station is a priority	Understanding the priority of the radar station	Priority based on a single factor (i.e. only radar with 3-D measuring)	Simple calculation of the radar station's contribution to the overall coverage.	Station is considered against overall objectives.
5  Evaluate > Ultimate Goal	Evaluate implications of not taking any actions	Understanding of consequences of the erroneous station	Consider the consequences based on the correct understanding of the information	Consider implications based on previous consequences	Consider implications by hypothesing possible consequences
6  Interpret > Goal State	Determine if radarstation needs to be taken care of	Decsion is made to either take care of station or not	Protocol used to determine if radar station should be handled	Protocols and exceptions made by considering past experiences to conclude if action is necessary	Deviations from protocol by considering the overall objective
7  Define Task > Task	Determine what action needs to be taken	Proper course of action is selected	Determine method based on single factor (e.g. type of malfunction)	Determine by using simple rules to balance workload (e.g. TSOP and LbeVed busy, fix station yourself)	Determine actions by considering what actions have the greatest positive effect on overall system purpose (TSOP is idle)
8  Formulate procedure > Procedure	Determine which station to implement the actions on	Radar Station selected	The radar stations is selected in the priority order	The stations is selected in priority order, unless new information is received	The radarstaions are selected based on the greatest effect on overall system purpose

**Figure 33: Optimization of radar stations**

#### 5.5.4 Summary of the WCA

When operators are trained, they learn the functions on recorded information. This can have the effect that the training of the operators is made by trainers to cope with situations that will arise in the recorded time intervals in the airspace. One of the most difficult parts of an operators work is to be critical to the information on the screen (i.e. not trust that everything is shown and that everything is in the precise location that is shown on the map). (Operator 4)

Using new functionality of finding information is sometimes difficult, during normal operation there is no spare time for exploring all menus and sub-functionality. To learn all new functions there must be extra training where different parts of the system are used and the operator has a chance of learning what the system is capable of. (Operator 3)

Much of the focus in this report is directed towards identification of a track, and this section is no exception. Looking at Figure 32 we can see different types of behaviour when a track is being identified. The different types of behaviour all need to be supported in the system.

## 6 The Compact C2 system

*The Compact C2 system described in this chapter is not yet implemented and should be configured to situation awareness, surveillance and for weapons control. This thesis focuses only on the air surveillance configuration.*

### 6.1 The whole Compact C2 system

The reason to develop this smaller and compact version of the bigger C2STRIC is based on the fact that not all countries want to invest in a new full scale system for airspace surveillance and only need to add functionality to their air space defence system already implemented. The system should also be used for evaluation and testing of functionality of a SAAB defence system.

One of the main reasons that this C2 system is interesting is its capability of using the tactical data link (TDL), Link 16. The link is currently being used by actors participating in joint warfare in NATO and the link is difficult to manage and use, for an effective participating in joint warfare, participants are required to practise using the network. That is why the system comes in handy, it helps own forces to practise using the TDL.

The Compact C2 system is supposed to be in three different configurations; situational awareness, surveillance and weapons control. Depending on the individual needs of each customer, different configurations can be bought and if the needs changes, the configuration can easily be expanded or limited. But it is not only the functionality of the system that needs to be adapted to each country; it is also the level of integration of the system. The new system should have three levels of integration. The first level is a complete stand-alone configuration where it has no connection to other C2-systems (one reason for this is not to affect national or international rules of connecting different secret systems). The second level of integration should be a fully integrated functionality within existing C2 system (one reason for this is enabling each country the ability to the use functionality within their own system) and the third level of integration should be a deployable system that can be transported and placed on different locations and provide full functionality of a C2 system (e.g. in a shipping container) (and the reason for this is that countries sometimes needs to operate outside where they normally operates).

As stated above, the system should be configured for use in several different settings (e.g. tent, Hummer, in the field and shipping containers), this puts demands on the interaction tools and screens to be able to show and interact with the system. In the next section the three different configurations be discussed and after that, the level of integration and the adaption to contexts.

#### 6.1.1 The situational awareness configuration

The situational awareness configuration is used to display data gathered from a joint network. The main purpose of this configuration is to deliver information from the tactical data link (TDL/ Link 16) network to commanding officers, providing the information needed to achieve correct situation awareness. It is by that functionality a very basic screen with a crude interface, allowing very little tools for creating the RAP and leading forces. This configuration is used to receive



information gathered by other sources and use that information for creating a more informed SA. The system does not allow the user to add information

### 6.1.2 The surveillance configuration

The surveillance configuration expands the situation awareness by providing external sensors to correlate with the information received from link 16. The sensors could be *external PSR stations* or *SSR station* (with CAA (*Civilian Aeronautics Authority feeds; shows information sent from civil aircraft*)). In this configuration there can be operators responsible for compiling the recognized situation picture, much like the work in C2STRIC.

The information (plots) coming from the radar stations into the TDFE is dependent on the country's infrastructure. If the air surveillance configuration is to receive plots from local radar stations the system must be adopted to the local infrastructure. The strength of this configuration is that it allows for creating the RAP, it sends information and if own sensors show something other than what is on the tactical picture, the system can help sorting out the identity of the aircraft.

### 6.1.3 Weapons control configuration

This configuration is the most complete of the three configurations, in addition to the situation awareness configuration and air surveillance configuration, there should be support for controlling the air and ground based air defence. When controlling the air based defence the system should be capable of contacting own fighters and guide them when they are operating in both practice and fighting situations, and also lead ground based air defence (GBAD) with target designation, defend sectors and text messages.

### 6.1.4 Summary of the Compact C2 system

The system being developed has three different configurations and the functional purpose of the three configurations can be seen at the top of the AH-hierarchy in Figure 34. The SA configurations purpose was to deliver a RAP, which is the first box in the top level. The RAP is then used to achieve superiority in information, the next functional purpose in the AH is expanding the system to both include a RAP and tools for surveillance (contribution to the RAP). The third configuration of the system includes both of the previous functions and also includes functionality for weapons control (leading friendly forces and communicating with participants of the Link 16 network).

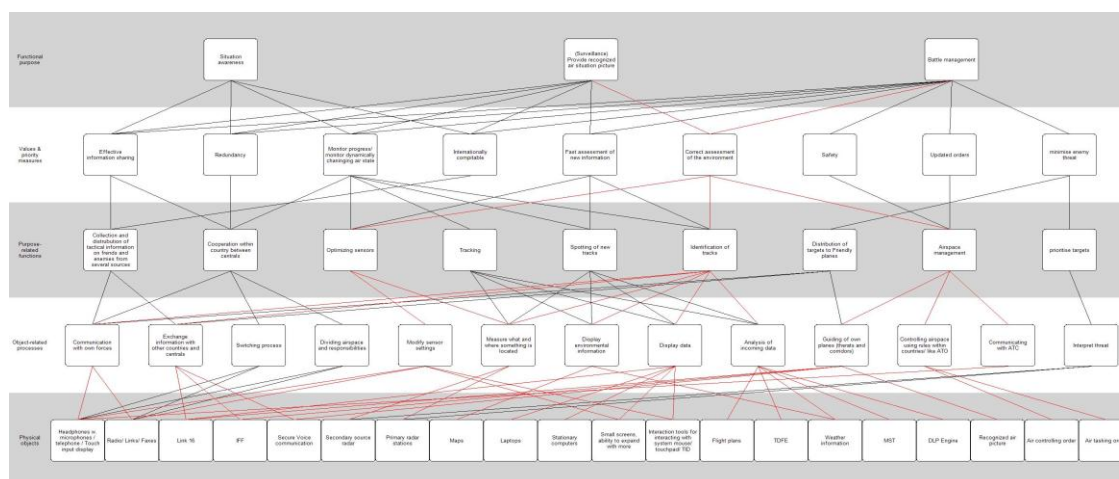


Figure 34 AH-illustration of the Compact C2 system

The AH in Figure 34 with all three configurations is large and complicated, for the sake of this thesis, as stated in the method, the focus is on the functional purpose in the centre (the air surveillance configuration). The purpose of this picture is to show that all three systems have links, goals and functions in common and that examining all functions would be too complex for this short thesis. Details of the boxes' contents is not relevant at this stage, instead a more detailed figure of only the air surveillance will be presented in the next section.

## **6.2 The air surveillance configuration in the Compact C2 system**

The Compact C2 is a modified system of the C2STRIC system, this means that functionality has both been removed and added. For a comparison to be made of the air surveillance configuration between the two systems, the air surveillance configuration is explained in this section.

One of the goals when creating the system is to make it easier and remove infrastructure and unnecessary functions. Another goal of the system is increasing the grade of automation (make it a choice to let the system carry out certain features). It will not differ so much from the C2STRIC system, but basic functionality will remain intact.

An AH of the air surveillance system can be found in Figure 35. One important fact to notice is that although the boxes at the bottom remains, some of their contents have changed from the AH of the C2STRIC system.

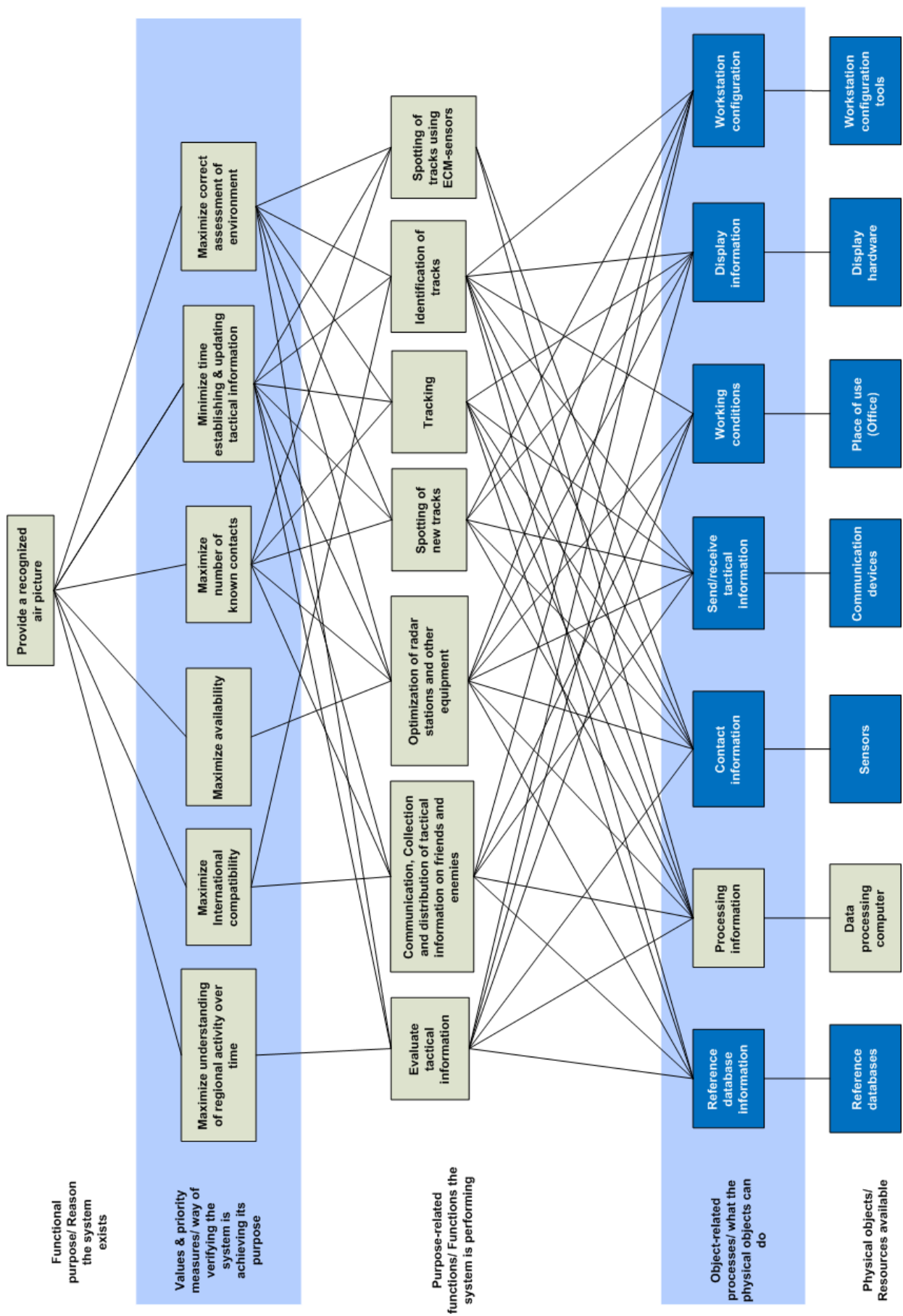


Figure 35; AH for air surveillance in the Compact C2 system

The blue boxes in Figure 35 represents that devices and their corresponding process has changed (some of the features has been removed). The reference databases (furthest to the left) consist of different parts, where some parts are an option that can be added if a customer wants extra functionality. The current database consists only of a map and has no flight plan information, no telephone catalogues and no manuals.

The data processing computer functions and use has not been changed when developing the new system.

Sensors will change from the C2STRIC due to the fact that the new system does not use the same sensors. This new system can be connected to the backbone of customers existing radar stations or have smaller, basic sensors. This means that the abilities and functions of Swedish radar stations cannot be transferred directly to the Compact C2.

Although the exchange information box is blue in the picture, much remains unchanged. The system should be able to receive information from several different sources all connected through the Link 16 network. Changed communications is that sensors depends very much of the customers infrastructure and radio contact will also be very much dependent on external communication devices (e.g. radio).

The place of use will be varied with the new system, no customers have started using the system yet, but an analysis of needs done by Saab explains that the system should work in altering conditions and settings. This could mean that the system is set up in an e.g. tent, used in a car or shipping container. These office places have the potential to drastically change the working conditions (this will be further discussed in section 7.1 *The differences between Air surveillance work with the C2STRIC system and the Compact C2 system*).

The display hardware can potentially change for the Compact C2 system compared to the C2 STRICS, a laptop version is planned, but the system can potentially connect bigger screens if necessary. The TID, intelligence system screen, internet screen will however disappear.

The workstation configuration tools may encompass different interaction tools for entering, selecting and interacting with the system (e.g. touchpad, trackball, keyboard, mouse or touch input displays).

## 7 Discussion

*In this chapter the information from the analysis will be the foundation of a discussion of the Compact C2 system's design. At first the differences between the systems are discussed and then design implications from the analysis are presented and lastly some general HMI points are presented. The suggestions for design should not be interpreted as the only way to solve an issue, they should be seen as the author's thoughts to support air surveillance work based on the material collected in chapters 5 and 6.*

### 7.1 The differences between Air surveillance work with the C2STRIC system and the Compact C2 system

Figure 34 illustrates that the three different configurations of the CompactC2 system uses the same kind of functions to some extent.

- This means that to save development costs, the system can be configured into a single hardware system. For delimitations of customer's products, a physical key could be used to decrypt and unlock features in each configuration. If a customer only wants the basic SA, they are unlocked in the software with a special key. But it is not self-evident that a customer who needs to direct his own fighters through a link 16 compatible system also needs to compile a RAP.

Both the grade of integration and the change of working conditions are likely to affect the systems hardware. A change of working conditions will in turn affect interaction tools of the system. Moving conditions requires adapted tools (e.g. a touchpad or a trackball can handle moving conditions).

- Support for easy connection of new interaction tools depending on conditions are important for the system, the operator would then be given the luxury of using the interaction tool that feels most comfortable (an easy way of connecting new interaction tools would be through Bluetooth).

The grade of integration with a customer's system is a factor that affects the system to a great extent. Different integration levels will also affect the interaction with the system, this type of changes in interaction is very difficult to analyze without a real system and real users in different levels of integration. Design suggestions for the hardware to cope with different levels of integration are difficult to analyze without actual conditions and needs. Through interviews with SMEs there were expectations that the system's ability to be easily expanded by the customer was important.

- Several different ports could allow the system to be expanded with minimal work. For example; when placing the simple laptop version with the SA configuration and touch pad interaction in a tent, and using a key to unlock the surveillance configuration, it could be possible to connect screens, radar stations feeds and effective interaction tools (i.e. a mouse). Connecting the system to a customer's infrastructure and integrating the system requires an understanding of how the customer's ports and connections work. An adaption

could be made to specific customers needs after an analysis of the customer's connectivity abilities is made.

From Figure 35 we can see that changing working conditions may affect the hardware, where laptops and laptop-screens can be used. An operator using the Surveillance configuration in the field may not have the luxury of using big screens. Small screens and changed interaction tools could mean that the interface needs to be adapted to new working conditions. A second fact derived from Figure 35 is that using the system outside office working conditions (e.g. at night) also affects the how the information is displayed, a sharp backlight from the system may hurt the eyes of the operators and the interaction tools (e.g. keyboard or mouse) may need lightning to help operators find them. A third consequence of the systems mobility is that it may affect the reference data used in the system. In Swedish air surveillance work uses short notes on the side of the screen as reminders and documents describing procedures in paper formats. If the system is to be mobile and used in darker conditions, a touchpad could be used for notes and store procedures or what is really interesting, the need of the notes must be studied and support for these references could be supplied by the system (e.g. post-its on the desktop). A fourth point derived from the working conditions is that, when the system is to be mobile and moved around, there can be shocks and bumps, it is therefore important that the hardware is specifically design to withstand impacts. The same goes for easy containers to move the system with. A fifth factor to take into account is that there is no office conditions concerning heat (temperature can change very much depending on customer) and weather (if used outside, the system must have very good lightning if there sun and withstand water in case of rain).

The identification process will be difficult without flight plans, the combination of flight plans and the transponder code is imperative for a fast, automatic and reliable identification of e.g. civil airlines. If there is no support through the system, the aircrafts IFF-codes must be connected to the flight plans by calling the responsible ATCs; calling local ATCs and other responsible will then be an important task of this configuration and the system must therefore have very good communication means. The system can provide a database where it is easy to see who to call and what information to ask for and there should be common reference points with local ATC for supporting communication.

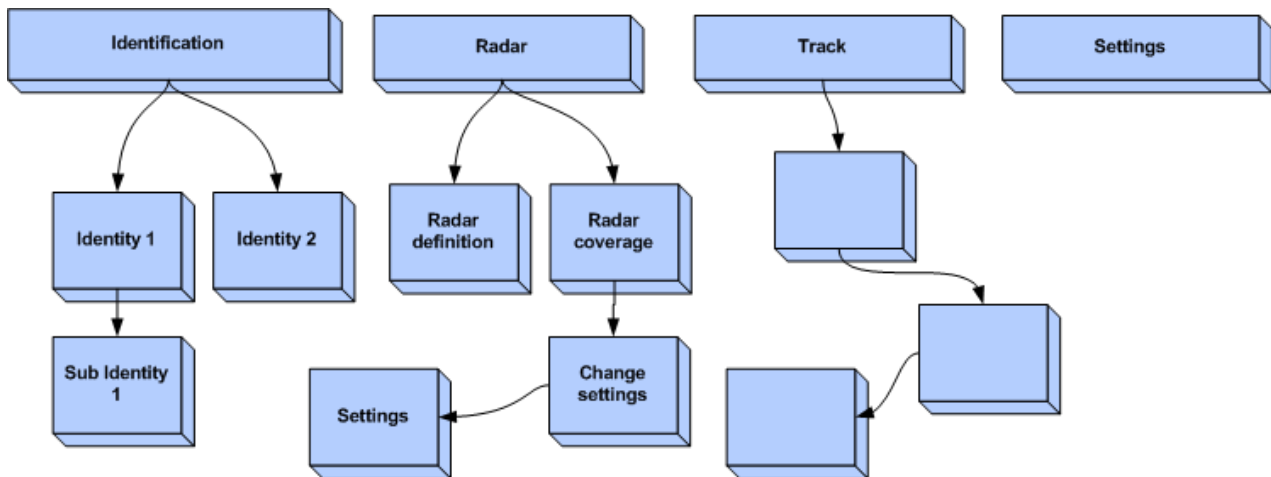
New communication possibilities could be needed. If there is no built-in support for communication through the TID in the new Compact C2 (which is used in the C2STRIC for interaction with communications) the system has to support communication in some other way.

- The system can provide information on who to call through a reference database and make the call using an external communication system, or the TID could be configured to work with a simple radio that can use mobile connections to communicate with civil ATCs and other civilian instances.

Looking at the box for the screens, it is clear that different sizes of screens may vary with different configurations (as mentioned earlier). When a screen size changes, so does the interaction with the system. Design suggestions to counter the new interaction patterns could be:

- Different interfaces could be accessed depending on the size of the screen. Larger screens can have toolbars and shortcuts, whereas smaller screens can have current navigation

systems, or a new more compact navigation system for example like the one illustrated in Figure 36. In this figure functions are placed in a search pattern and an operator can find correct function by logical path. If the configuration is moving and a mouse can't be used, another option is to expand the use of the keyboard to help with shortcuts into the menu, that is, if the menus and submenus (as well as all windows) contains key-combination shortcuts (the shortcuts can be displayed next to the entries when holding down the alt-button).



**Figure 36 quick button interface support used to traverse through hierarchies of functions and windows**

If the system is connected to new sensors and perhaps even a customer's backbone of radar stations, interface must be designed to support new options available for configuring the sensors. Information gathered from the generic decision ladder for optimization of radar stations shows that position, type, range etc. (further information of what is needed can be found inside the decision ladder) are important factors when a radar station is configured, the new system would become more valuable to operators if it could support operators in configuring radar stations for correct coverage of airspace. Due to the fact that no information of what radar station will be used in the new Compact C2 it is too early to specify exactly what information is needed, the generic decision ladder in Figure 27 is based on work in the C2STRIC system with its radar stations and can only point in the direction of what to search for when studying how to develop support for new radar stations.

Comparing the AH from Swedish air surveillance work with the Compact C2 some of the functions is planned to not be used. One of the functions that are removed is the ability to see mission specific data. In Swedish air surveillance work the information was, among other things used to verify correct radar coverage over interesting sectors and help understanding of activity in the airspace. This information may need a new way of being represented to the operators. Another change in the purpose related functions is the ensuring of system integrity, without the ability to control radar stations, the protection of the stations needs to be handled by other means. Object related processes that have been removed is guides to human conduct, by not knowing the new customer, the guides and many constraints are unknown and the system cannot be adapted to suit work in other systems if the guides are very inconsistent with Swedish guides.



## 7.2 Design implications

Design implications from all five levels are presented and lastly some general HMI results, not derived from the models are discussed.

### 7.2.1 Work Domain Analysis

One of the boxes in the AHs is international compatibility, this can mean a lot of things, and in this case the box refers to technical compatibility. The technical compatibility is based on tactical data links (TDLs) providing the ability to share information, but these links also requires some degree of process compatibility (i.e. not just technical standards but operating standards of how to use them). Using the TDLs affects demands on the identities that can be used, together with affecting whom are responsible for reporting position and classifying a track (support to the operator with setting identities and handle conflicts is currently not fully implemented in the C2STRIC system, although that work is under way). This thesis has not focused on the communication process (there were no operators working on this area available for interviews) and is therefore not capable of making a statement of how the system should be designed to support the international compatibility. What this thesis can conclude is that the area is very important for the Compact C2 system due to the fact that it is marketed as an international compatible system and a study of this area would give important input to systems design. There are other factors that also need to be considered for international compatibility, currently only the Link 16 network standard is implemented, but there are more factors needed for the system to have the same type of communication as other countries. To ensure technical compatibility some functions are still needed such as secure voice communication and support IFF mode 4. To gain more understanding of international work and how the information exchanges occurs, the send/receive function of the WDA would provide important information if it was put into focus when conducting an analysis. Exchanging information and being international compatible requires a deep understanding of how information is compiled to a RAP, during the work of this thesis no interview persons with international experience of this cooperation was found, and for a deeper understanding it is important to find an operator with this experience.

There have been advancements in technology when using the international data link. The Compact C2 could be prepared for a potential for development of the TDLs. Link 16 is today a network with a limited capability of transmission distance and a Compact C2 system should be prepared to expand and use Link 22 or Link 16 with satellite communication capabilities for a significant increase of the transmission distances.

In the AH the boxes representing reference databases and displays gives an understanding both what information can fit into the display and what different sources there are.

- Combining the understanding of reference databases with the screens, some basic conclusions can be drawn for the new Compact C2, if the customer has the same shape of their country as Sweden (long and thin), the representation of the map on the screen would benefit from the ability to upend the display. This would give the operator the advantage of showing more of the important area closer to their countries, where the sensors have coverage. Another point related to presenting the graphical information is the size of the screen. With the current interface, operators have several opened windows, larger screens would allow more functionality being displayed at once and minimizing the work of

finding correct function and thus, the screen size is important. The current two screens are 30" inch, and this thesis shows that operators' cognitive abilities can process all information presented on the screen. An evaluation of enlarging the screens could improve information displayed to operators and thereby increase their understanding and performance. A negative aspect of using today's two screens is that there is a wide bar in the middle of the screens caused by the wide frames. Since the resolution of the big displays has improved so much since the C2STRIC was developed (a statement from SME 2), one large display can be used to fill the same purpose as the two small. This would reduce the feeling of two separate screens, one for the recognized area picture and one for identification; it would become a single screen system. The internet screen is an important feature in the system and should be supported through the Compact C2, this screen enables the operator to seek information in a wider cycle and is perfect for new and unexpected situations, however the most frequently used sites contains information which could be available in the system, hacker attacks against governments and websites have provided enough evidence that sites, including the CMFV site can be hacked and information falsified.

The quick-buttons used in the C2STRIC system today is a tool that helps the operators gain easy access to functions and quickly carry out actions. This function is very valuable for operators, in the real facilities the keys are covered by stickers explaining what each button does. The buttons are configurable and information can vary to great degrees, an evaluation could be done if the quick-buttons can be replaced with another function supporting easier configuration. Today when an operator tries to remember a key they haven't used for a while, they have to search for the key definition in menus and then look at the quick buttons to make sure they have the correct key.

- One design suggestion is to support this work is to use a small TID to display what each key does. The TID would help the operator with remembering programmed functions instead of searching for that information in the C2 system. The technology with TID is already implemented in the communications panel of the C2STRIC system. A TID could help the memory of the operators and this would lessen the cognitive burden of changing a keys function and thereby allow for more experimenting with finding new functions to make interaction more effective. A TID have some drawbacks, and replacing the quick buttons with a TID would mean that speed and tactile feedback disappears, another option to evaluate could be an OLED keyboard with programmable buttons, where both speed and tactile feedback remains.

Air surveillance leaders constantly have to write reports on what is happening in the system. This takes a lot of their time and focus. Constant interruptions and a slow support system distract the air surveillance leader. One design suggestion to support this function could be:

- Basic information could simply be printed and then scanned into the other system and read if the systems cannot be connected to each other. It is not unlikely that the Compact C2 system could be used as base for surveillance reports and functions to support that work is therefore important to consider.

When it comes to sensors, the C2STRIC is not currently using any sensors for the new ADSB system. Support for this system could be used in the new Compact C2. The technology is cheap and the information can be valuable for helping the understanding and identification process. Extra sources of information are very valuable for operators during the identification process and the decision ladder shows that ADSB has the potential to be a source to help make the information more reliable.

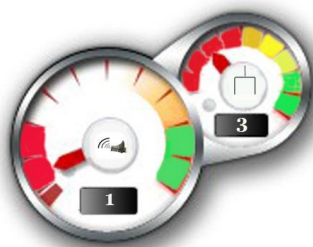
Another fact that was revealed in the WDA is that Swedish air surveillance operators sometimes use ESM from external sources (FRA, Erieye). If the Compact C2 was equipped with the ability to be connected to signal surveillance, there would be much to gain in the identification process and expanding the number of sensors helps the operator with more data when making a decision.

### 7.2.2 Control Task Analysis

One important decision an operator in the air surveillance system makes, is deciding if there is a risk that an unidentified aircraft passes the interception line. Deciding where the interception line is can be hard; it depends on speed, and heading, state of readiness and location. Today the workers are helped with a measurement line appearing when the operator presses the shift key. The line should not be left out of the Compact C2 due to its many uses in all three configurations for measuring distance and see headings from different points in the map, especially when a track is added and updated manually based on visual reports.

- One design suggestion to further help the operators when determining an interception point would be to show an “interception line” when a track is selected.

From the decision ladders we can furthermore gain understanding of when information is needed. For example, speed, heading, altitude and track quality is very important when a decision of identity is reached. The speed and heading is shown by a vector coming out of the track, for detailed information about the track the operator looks for a window located close to the frame (and the edge of the RAP) where the information is gathered and comes in numbers. To gain information of the track quality, an operator always has to locate the information in the extra window. In the Compact C2 with many novice operators it would be helpful to support several types’ cognitive functions for easy determination of track quality. This can for example be done with Figure 37 shown below (the figure will be further discussed in section 7.2.5).



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**Figure 37 measuring the track quality**

In order to gain more information of a track (e.g. track quality, call sign) the track must be selected. With the C2STRIC tool there are two ways to select the track; hitting the track with the cursor and hit exactly right or right-click with mouse in the area close to the track and hopefully the track has a unique id (several cases were observed when the ID was not unique) that can be

selected from a dropdown menu. Design suggestions to make it easier to select a track to gain more detailed information:

- Additional support for the selection process could be hooking through a selection box with dotted lines (and everything inside box is selected, the operator can then chose from a small box which he wanted). This selection box could also be useful for selecting several tracks in an area, this would allow for easier comparison of tracks when several are heading for Swedish airspace. Multi hooking could also be used for easier deletion of several objects in an area (could be used if e.g. a radar station was malfunctioning). Another observation made during observations of operators was the risk of missing a selection of a track and in a stressed situation the operator could mistake the old information in the details window for information belonging to the wanted track. A solution to this could be a de-selection option, which would also have the effect that the information-window would look cleaner (less information for the operator to take into account when moving their focus to different parts of the system).

A detailed control of the interface should take place to validate that the information needed for each step in the identification process represented in the decision ladders (from section 5.2.1.1) exist and is clearly visible without too much searching inside menus and windows. Organizing the information on the screens to have less windows and a clear grouping is important to reduce the work of handling window sizes and positions, together with identifying hidden functionality. When one radar station needs adjusting, the worker should be able to open *one* window and with the press of a button and get all functionality in one single screen grouped together. The grouping should also involve the taskbar, when programs are minimized, they should be placed in clear groups (e.g. Figure 38).



**Figure 38 an example of the grouping minimized windows**

The decision ladder of the optimization of radar stations (found in section 5.2.2) shows that the process is fairly straightforward, however, during observations of operators performing scenarios, there could be as much as seven windows open when performing radar configuration. A deeper analysis of the optimization process should be used to reduce the number of windows needed to complete the action. However, because of the great uncertainty of what radar stations the Compact C2 will have, this type of analysis has not been made in this thesis. When there is a clear definition of what radar stations should be in the system, an evaluation of how the interface can support their abilities can be conducted.

Calculating the importance of a radar station is important when determining how to optimize sensors, another important fact is to find common errors and faults of a particular station. Since the weather and sun can affect the coverage this information could be displayed and thus allowing the operator to gain a deeper understanding of why radar stations shows faulty information. Design suggestions to support the optimization:

- When deciding how important a radar station is, the system can support manual entering of which stations are redundant (have a backup to cover its area). This would allow for a fast

evaluation if the station needs to be covered by other stations or surveillance equipment. The operators working with the C2STRIC system had some basic knowledge of common errors with a station and it would be a big help if there is a way to bring the information up on the screen when an operator is troubleshooting a radar station. Other information that the system can provide is when the sun sets over different parts of the country, this together with weather conditions can affect radar stations. The weather factors can also have an impact on the behaviours of planes (e.g. circling and waiting for good landing conditions or taking an unexpected turn to avoid a storm).

The information coming from the radar stations is currently displayed when a station is selected and a window is opened. One design suggestion to easier show information of a selected station:

- The information tab to the side of the RAP containing information of a selected track could change to show information of a radar station. This could for example be done with a tab on the top being selected and a common interface showing relevant information that can be used to troubleshoot or control optimal performance of each station.

### **7.2.3 Strategies Analysis**

Using the information flow maps some basic understanding of air surveillance work was gained and transferring that to design can be done through dialogue modes or process flows. This means that the information flow maps give a direction of how to group functions to support work flow.

The filters<sup>3</sup> of the system proved to be an important HMI tool when performing functions such as spotting, understanding and controlling activity of tracks. Using filters in combination with the Picture in Picture (more than one window with the RAP open) mean that different filters can be applied on the same RAP to show other information of a specific type more clearly. This however required three windows with filters to be displayed (one for each Picture in Picture). This filter function for three windows took very much space and focus. Design suggestions to support this strategy;

- Reduction of the filter windows is to allow them to be tabbed, when a operator needs to compare filters to each other they just grab the tab and drag it to desktop next to the window they wants to compare it with and a new window is created.

More important was that it was difficult to see what was hidden with filters in RAP, the operators always had the same settings, but if a filter was changed and then forgotten no information of different settings was displayed. Suggestion for supporting the operator with information:

- For displaying the fact that a filter which the operator normally does not use in a view is turned on, a notification can be made (e.g. a little bar at the top) and a notification indicating either how many is shown (e.g. Showing 13 of 400 planes) or which are hidden (e.g. not showing: 133 planes of type civil) could help operators to more information of how the real world outside the system looks. There should be information of tracks

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<sup>3</sup> filters are used exclude certain tracks and other information being received from sensors/TDLs being displayed on the RAP.

excluded from other centrals sending information, without that kind of information operators in the Compact C2 can't evaluate if they are seeing everything in the airspace.

When an operator searches for flight plans there are several systems used and several systems result in several different ways to search for a flight plan. Although it is very ineffective to search all, this often occurs in a situation where something unknown is heading for Sweden with an IFF code and a fast identification must occur (thereby putting a lot of pressure on an operator).

- A suggestion derived from the strategies analysis shows that the flight plans could be collected into one single system; this would make the search easier and thereby giving more time to make a fast decision of identity. Another way to solve problem with many databases is; instead of the operator writing in the IFF code in all windows and places, it would help the operator to right-click and select "search flight plan", and this would search all sources and display results on the screens. One way to represent this information in a Compact C2 would be to place a large button on the TID with the responsible ATC to call for more information, alternatively all information of flight plans could be inside the Compact C2 system, and this would enable fast identification of all activity with IFF-code in the airspace.

Sometimes the operators search for more information using the internet and one webpage used is [flightradar24.com](http://flightradar24.com); this page shows flights all around the world connected through the ADSB system where aircrafts send their positions using GPS. This extra source is unreliable (the reliability of the information is about the same as mode 3-questions used today, the operator has to rely on the aircraft sending correct information, the information can be made more accurately with signal triangulation and other security measures), but could, if implemented in the Compact C2 system show very detailed information of all aircrafts that uses the new system for identification. There is currently no information of any other systems (no intelligence system and no internet system) that an operator of a Compact C2 can use, and one way to wider the information the operator can access is to implement some basic information from the ADSB system.

Support to the surveillance cycle should be evaluated. The cycle represents the different stages of work and is therefore very important to consider when design is being developed. One suggestion derived from the analysis:

- That there could be a few symbols next to the RAP, where a mouse over function could get all aircraft with known military transponders to blink once (or similar way to make identification easier). Furthermore there could be a counter of how many military or neutral aircrafts are visible next to the mouse over symbol. There could also be the ability to fix certain sectors for showing how many aircrafts are active in a sector (in Swedish air surveillance work such sector could be e.g. Finland). The concept with mouse-over can also be used on planes heading for Swedish airspace and one for lighting up airplanes **deviating** from their flight plans.

### 7.2.3.1 *Tabs with shortcuts developed with strategies in mind*

There is a need to structure the information in the Compact C2, and this short section presents tabs with shortcuts as a design suggestion, this suggestion is not tested and evaluated with users of the Compact C2 system, but is a way to minimize the use of windows.

For organizing the information found in top menu-bar, there should be easier access and one way is through tabs in the Compact C2, this makes sure that not all information is hidden in submenus and hard to find (although even tabs hides information).

- The tabs could be designed with information flow maps representing the functions carried out inside the system. A CWA of several functional purposes from Figure 35; AH for air surveillance in the Compact C2 system) can reveal what actions must be completed to conduct a function. By displaying only relevant shortcuts when a function is conducted, there is less hidden information. The functions under each category in the tabs could be represented with symbols for supporting more cognitive functions. A toolbar on the left side of the RAP could hold all important features used when editing information in the RAP (e.g. notification symbols to mark interesting activities or tracks). One entry for the toolbar is, that after identification, there could be support to check a special box for the company not to empty itself out when coverage is lost (this could prevent losing track of an important aircraft).
- The right-click drop down menus could also have support for keyboard shortcuts (e.g. alt + Parts). Sorting the drop-down list and removing unnecessary entries is a very big job which is not encompassed by this thesis, but is imperative for an interface that is adapted to users. One way to evaluate this was presented in chapter 3.1 (Analyzing Command & Control Systems), and is called HTA.

### 7.2.4 *Social, Organizational and Cooperation Analysis*

The handover of the complete RAP takes a lot of time in the C2STRIC system. When handing over the RAP to another central, a number of actions needs to be performed and much communication is needed (handing over own age of tracks means that although both centrals can see the tracks, only one facility can "own" the tracks and the responsibility for reporting the tracks position and identity). Design suggestion:

- The handover can be completed by a simple dialogue saying "leave to" and a symbol turning green when ready to send the RAP and transfer the responsibility, "receive from" and a symbol turning green when ready to receive.

When seeking information of where an aircraft has landed in the C2STRIC system, the operator needs first to turn on the airports filter (moving the eyes away from where the plane landed), then localise the position where aircraft disappeared, then open telephone-book to find a number and then dial it through a number of buttons on touch-display.

- A design suggestion to help operators in Compact C2 when conducting the task is; a right click in the picture and "show nearby airports", the airports are displayed and right click on the correct airports gives the option "call" (or just mark an airport in the situation picture and the number immediately comes up on communication-touch).



Information of what role an operator is logged in with is important. This information is used to make sure that the correct role is chosen, if the operator has the wrong role, some actions were blocked and other centrals could not contact the operator. Another point that is associated with this is that an evaluation is needed to determine if it can be of use to also show an operator's names to another central. When something happens during operation with two centrals online, it is important to search for the error and the operators tries to adapt their language to what they believe the other persons knowledge-level are. In Sweden most of the operators know each other and understand the knowledge-level of the operator they are talking to if they are given a name, if the information of who the operator was talking to, the error seeking could be reduced.

- The error seeking process could also gain from showing the settings and areas of another central. This fact became very clear when both centrals tried to set up their systems for a shared responsibility a Swedish airspace, and they could not find the setting that were wrong. The function of setting up areas of responsibility could also be helped by the system by preconfigured filter settings.

When operators are looking for information about why the system is acting strange in certain areas (e.g. tracks not shown but radar stations are working) of the RAP, it is not always easy to find the cause. More information is sometimes needed about what changes and settings have been made by other operators in the area. Design suggestions to support this process:

- A notification system is could be used to add notes of how the system functions and what changes has been made in the system. Changes that affect the whole system (e.g. radar station configuration to cover a specific area, radar station in standby or excluded areas) could be saved in a configuration list managed by the Compact C2 system. If an operator selects an area the post affecting that area could be highlighted and if a post is selected the area affected could be highlighted. The system could also contain information of the operator who made and the notes from operators could be added. This would enable all operators to understand what is happening in the airspace and no changes would be forgotten.

Today, much of the reporting from operators in the air surveillance battalion took place after the shift had ended or in a handover to another operator. Notes taken with pen and paper are used to remember important changes and evaluate the system with the air surveillance leader. Design suggestions to support reporting:

- Instead of using their notepads for making notes, the message window could be used. This action would enable all operators to see notes and perhaps start a thought process of improvements and creating more discussion of how to solve the problem. This would also be a sort of fail-safe, if an operator forgets to report something in a handover, the information could have been noted by another operator in the system and placed in important notes. The notes could also be printed as reports and studied to see if deviations from normal conditions occurred (e.g. the same radar stations break frequently or very difficult to contact a specific ATC). Making the operators use electronic equipment for notes is however difficult, using the Compact C2 for these annotations, the operator has to stop his current process, start the annotation functional and write, this process is much

more difficult than using pen and paper. A design suggestion that would support these annotations is using voice and a specially designated microphone to record messages that a computer program then transcribes and at the end of the shift, the operator reads through and corrects.

- Another factor to consider, associated with the briefing after a shift is that, reporting errors and strange behaviours of the system could benefit from a system -recording (e.g. one day at a time). This would enable the operator to note the time, label it and give to commanding officers who can extract the movie and allow the operator to verbalize and graphically explain what occurred (this could for example be used to describe how the operators expectations of what is going to happen differs from the engineers understanding and programming of the system). As a training and development tool, this function would produce a lot more information than just operators describing a phenomenon that is hard to recreate.

When several tracks are heading for Swedish airspace, a prioritization of the tracks is needed and sometimes the tracks must be divided among operators. There was no clear way how to coordinate the division of airspace and companies. A support for the LBEV/operator would be very helpful and one suggestion for support is:

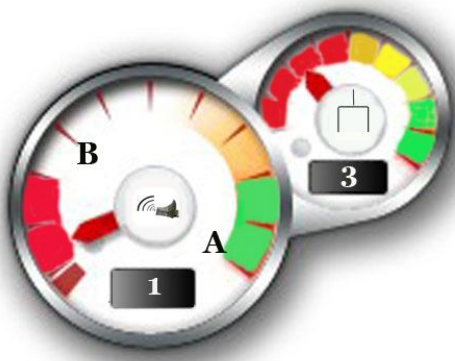
- If an operator takes one track and starts working, the track could receive a symbol and the other operators helping with the identification can choose a different track. Today the work is carried out by saying the numbers of the tracks or giving approximate geographic references. The toolbar suggested earlier could contain tools for completing this function. Or divide whole airspace sectors with triangles.

### **7.2.5 Worker Competencies Analysis**

This section discusses findings using the worker competencies analysis from section 5.5.

In the C2STRIC system today the track quality measurement is a small box on the side of the RAP. This function is however imperative for evaluating if the information is correct or not. When reading the track quality there is just a number with no implications of its meaning. A design suggestion to improve understanding of the measures:

- To help determining of the track quality a gauge could be used as an example is shown in Figure 39, it should be noted that this is only an example; a more compact meter would also fit into menus and small tables where this figure will not. In this meter a max and a min value is determined and a green level is used to indicate when the information is trustworthy. Two meters are shown; one is for radar quality and the other for track quality.



**Figure 39 measuring the track quality**

The gauge in Figure 39 supports the knowledge (symbol), skill (signal) and rules (sign) behaviour of an operator;

❖ **Rules (sign):** the table below is used to explain the behaviour.

If track over area of responsibility	If A and number = 15, Good
	If B and number = 4, find more radar stations or evaluate cause
If track not over a area of responsibility	If B and number = 4, OK

**Table 6 rules behaviour when observing the flow meters**

❖ **Skill (signal):**

-The value should always be 15, meter at full. The arrow can be used as error signal if it deviates.

❖ **Knowledge (symbol):**

-If stations are adjusted and no improvements are measured, evaluate functionally (e.g. track might not be an aircraft or radar station malfunctioning).

The system is currently good at spotting and tracking companies, which can result in the operators relaxing and letting the system take charge of the functions. This could lead to aircrafts not being spotted or properly tracked if the system misses something and the operator is left out of the process (Hawley et al., 2005). One suggestion to train operators doing the manual work:

- Now and again the automated tracking and spotting can be turned off, allowing the operator to train the functions manually and maintain the correct way to search for tracks.

Indications of faulty radar stations is currently being showed in red/white/blue, these indications on the map helps the operator to spot errors and locations of the stations.

- The type of station could also be used in a small label to quickly determine what actions to take for a novice operator (who might have difficulties coupling type and position of radar stations).

The C2STRIC system uses warnings and notifications moderately, not many warnings are used to help the operators note something happening in the system. For example, the threat evaluation in identification process has no support from the system. This area could be developed in the new Compact C2 system to support operators to classify threats. Even though the other two configurations of the Compact C2 (the weapons allocation and situation awareness) hasn't been in focus during this study, there is material pointing to the importance of a fast threat assessment in these two configurations as well.

One type of warning used was a popup window (occurred with faulty SSR, Hijacking etc.), this kind of warning disturbed the operators and they were forced to close the warning<sup>4</sup> in order to continue with their current action. This behaviour was repeated so much that the actions appeared to have a very short decision ladder<sup>5</sup>; in real-life situation these warnings would appear when exercising fighters who tries start-up procedures and test their systems sends these messages. This could mean that the behaviour of closing the popup would be so automated that an important situation would be missed. A design suggestion to diminish the popup warnings:

- One way to correct this would be to link the warning with locations, e.g. red rings on area in situation picture where the warning is derived from (and expanded into a warning box if selected) with the potential to disappear with hitting a small part marked with normal symbol for closing windows. If there came a small symbol next to the aircraft the operator could easily determine if the alarm was important, also which operator should deal with the alarm depending on sector, not all operators need to see the warning. When the window appears the codes should be explained and a small guide with instructions could be linked through the online manual. The operators should know course of action after training, but the explanation could be used to trigger memory, which would be useful since the warnings should be rare.

To cope with the international compatibility most C2 systems use uniform identification symbols. If one country however wants to use their own symbols they need to use an overlay used only for own centrals as a national modification of the RAP, this means putting their own symbols as an extra filter over the previously defined NATO symbols. This would allow operators to identify companies before they breach borders of national airspace and not only auto-accept symbols<sup>6</sup>.

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<sup>4</sup> This behaviour was observed when operators evaluated the system in the Saab factory and no operator interviewed had experienced the warning in their central because it was relatively new

<sup>5</sup> The decision was made very fast and require little decision of whether or not the information was relevant

<sup>6</sup> i.e. when a civil aircraft heads for the national border it is marked as friend on the NATO link, but that symbol is also used for friendly military aircrafts. Some nations uses their own undercategory of friendly to mark the track as civil. An overlay of identity not being sent and conflicts with the Link 16 information can be used within the national system.

This ability is used to allow the operator to easier surveillance interesting air activity by filtering out civilian companies.

It is important for the understanding of the link that the current load of the link is presented; the operator needs to know if there are tracks not being received due to an overloaded link. If there are missing companies due to filters or the link being overloaded, the operator needs to recognize the problem. A design suggestion to help operators making this assessment:

- When displaying the information on the Link 16, e.g. a flow meter (similar to the one presented in Figure 39) can show current information load on the link and upon selection it expands and shows all participants in the net and allows for contact (this would enable the operator to write a short message and describing what companies to exclude). Showing the filters is also an important part to understand other facilities settings.

From Figure 3 the three lines illustrating different stages of the engagement chain) and the AH of the Compact C2, we can see that it is important to locate all tracks early, sometimes it is good to find them before they become companies. A design suggestion to further help finding companies fast:

- A button used to make the new tracks<sup>7</sup> pop out (e.g. enlarging them), that is activated by a mouse over movement or a filter that quickly sorts away everything but new tracks.

### 7.3 Evaluating the system from the HMI guidelines

This is the last part of the discussion and is used to capture additional design suggestions derived from the basic HMI principles presented in section 3.3.1 (Interface design guidelines)

- When an operator hooks (selects) one track, there are benefits of not showing history of all tracks and longer history of the selected track (to judge turns, origin etc.) and hide all other track's history (in case there are several tracks in the area and the plot history becomes cluttered). For this function to be usable a de-selection function is important. To evaluate several aircrafts multi selection is needed (e.g. select two tracks and see if really old plot history shows that they were in a rote-formation and also if one track has become two and an evaluation of the tracks history is needed to determine which one is false). Another function related to the plot history is presentation of plots; when an operator specifies the length of the plot history, there should be an option to only show plot history used for calculations of a track (i.e. not plots from weather phenomena), this setting would allow the screens not to be cluttered by malfunctioning radar stations in problematic areas.
- Selection of tracks is currently a discrete function and requires a lot of precision (or right clicks in area close to hopefully find a track with unique id); a mouse-over function (that can be turned on or off) would give more "feeling" of objects. So when an operator wants to select a track, the mouse-over would give an easier understanding and response to which one will be selected.

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<sup>7</sup> Pending and tracks which has not yet becom companies

- The MST tracking settings is a very complex window where operators very rarely change any settings. A change of these settings would affect operators and wrong settings could render the MST to malfunction. Only deep knowledge of the MST allows for configuration, Saab often holds courses and training of the underlying functions of the MST, TDFE and link 16. If the window also had a functionality to reset values to default there would be less risk of the MST malfunctioning and the system would feel safer to configure. At most times the MST does not need to be configured, but for the Compact C2 no optimal settings has been found and therefore changes of the MST is most likely to occur, the optimal settings for the function is likely to be a iterative process and there could be functionality for saving several different configurations.
- If the Compact C2 is constructed without flight plans there can be no support to see that the flights deviate. Today this occurs by selecting an aircraft correlated with a flight plan and the details of the flight plan is drawn as a white line on the map (if that option is selected). If this function should exist in Compact C2, it could be improved with marking travelled path grey and marking descent (in e.g. a light blue colour), and climbing (with e.g. an orange colour).
- The handling of windows was found to take a lot of focus and energy from operators, other principles for handling windows cluttering up screens could be to use “sensitive” windows that places themselves on a free square and can help with a short millisecond stop when it reaches other edges to help with alignment.
- A Compact C2 system is not likely to have a TID. If this would be the case, ripples on the TID could be used to indicate that the gesture was recognized and the function selected (if any) could be marked in a dark colour to indicate that the choice is being processed. This function is not coupled with any information gained during interviews, this is a suggestion based on the basic HMI principles to give the operators a direct feedback of their actions.
- Timeline (of flight plans) to allow operators understand what is planned to affect their area of responsibility.
- To further help the operator with information there could be an icon next to target indicating the trend (i.e. target is rising or target is descending).
- Indicating that the system is operational takes a lot of attention, today there are two big blinking green lights. There could be a need to re-evaluate if this is the best way to display that the system is operational.
- The drop down menus are very responsive, this resulted sometimes in dropping out of menus, lowering the responsiveness would prevent the operator to start over when trying to access submenus. By holding down the alt button, the key combined with the correct entry on the menu could be showed; this would help a skilled operator who uses the menus daily. Also the dropdown menus needs sorting some kind of sorting and unnecessary elements should be removed to decrease non-essential actions.

- There should be support for planning phase, see what is heading, as well as history, to be able to rewind and see what has happened. This suggestion is however not a part by the general guidelines presented in section 3.3.1 (Interface design guidelines), this fact is from the SA definition. To increase the SA among operators this process could be supported by the system.
- The analysis points to the fact that all operators first course of action is to set a search area wide enough to encompass all radar-coverage, this unnecessary step could be eliminated.
- Direct manipulation of objects in the system is important (e.g. in order to correlate two different tracks, the operator could have the choice to drag the track and drop on top of another track to correlate with or hook a track and change its direction by manipulating the heading arrow sticking out of the track) this could support actions difficult to manipulate in degree fields with just numbers, more intuitive to do it by rotating the symbol.



## 8 Conclusions

*This chapter presents the most important findings and answers to the research questions.*

*The purpose of this thesis was to analyze a full-fledged system for air surveillance to inform design of a system with only the essential functions for air surveillance, where the design is well adapted to the work being conducted.* This thesis has had its focus on the structuring of information into the CWA framework designed in chapter 3 and this has been done successfully. The framework has been a very valuable tool for a structured analysis of the C2 systems. The framework has helped to find several differences and thereby guide design suggestions for the Compact C2 system. The analysis has further helped to develop suggestions based on the current work in the Swedish air surveillance domain on what the Compact C2 could contain to help with the operator's workflow. The collected material in chapter 5 and 6, used as basis for the discussion, can also be used for guiding future designs and help new programmers to gain an understanding of where their function will fit into the system. The focus on structuring and gaining information has had the effect that further research areas have been identified and design suggestions have been generated to support current work, but no design solutions have been developed in terms of code. Using this framework to further study the organisation would give information of how to enhance training of operators.

The first research question was, *“What type of analytical framework supports a system analysis and gives information to interface design?”* The framework chosen and used for the analysis was the CWA framework. This framework proved very good for analysing systems. The only drawback that was found was that it was very time-consuming for a novice user and required very large amounts of data to gain a complete picture. Using the framework has led to a large amount of data and it would be wise to continue to work with the data and dig out more information about the system. Delimiting the focus of the study early in the process is imperative for an analysis to be conducted in a reasonable amount of time. Also the opportunity to study work in real-life situations and have access to operators is very important for the analysis.

The second research question was; *“What is the working environment for an air surveillance operator during work in the full-fledged C2 (command and control) system?”* The working environment for an air surveillance operator is explained in chapter 5. The description contains five different levels of analysis and has a focus on primarily the identification process and secondarily on the optimization process. There were however many more functions and processes that were omitted by this analysis due to time constraints and further analyses are needed to fully answer the research question.

Another fact that influenced the description was limitations on how many operators that could be interviewed and the number of field trips that was allowed. There was a difference in the information gained from observations. One field trip to see actual work within the system revealed far more about the system compared to observations made at the Saab factory. One thing that was noticed was that operators omitted some steps that were recorded during observations in the field

(individual differences can be excluded, the behaviour was recorded also for the same operators that was observed in the field) when evaluating and showing the system at Saab. For observations of work in air surveillance it is therefore important to try and recreate conditions as realistic as possible at the factory. One step to do this is to use the cognitive work analysis, focusing on the AH and working conditions together with the interaction tools used in realistic scenarios.

The third research question was; *“What are the differences in the air surveillance work in the full C2 system and the Compact C2 system?”* In the beginning of chapter 7, a discussion of the two systems is made with the AHs as the basis for comparison. Working conditions was argued to influence the systems design to a great extent and several important areas for future research such as exchanging information was identified.

Finally the fourth question was, *“How can the Compact C2 system be designed to support the air surveillance operators?”* This question was answered in section 7.2 and some problems and suggestions were discussed. There is, however, a lot more analysis needed to fully support the air surveillance operator’s work. In chapter 7 I also argued for minimizing the use of several windows and stressed the importance of enabling more direct manipulation in the RAP.

*The aim of this study was, on the basis of an analysis and theories of interface design, produce input to an interface design that is well suited for the operating conditions and also supports cognitive functions, increases health and productivity, and promotes safety in a Compact C2 system.* One goal of the CWA framework is to provide guidance for interface design with a focus on the cognitive processes of operators. Safety of a system is accomplished by multiple factors. One factor towards the goal is to let the workers have the flexibility to adapt to unexpected situations. By letting the workers see the boundaries for safety and reliability they can plan their actions within the constraints when performing their activities. The CWA analysis should also give productivity to the system. This is done by designing a system where worker decisions are supported and they have the freedom to “finish the design”. This means that the workers are free to chose their own path and are not confined inside the “one best way”. According to Karasek and Theorell (1990), to improve health of the workers in a system, the most important variable is autonomy. It is important to let the workers do some things their own way, being forced into a narrow path of one “predicted best way” can have negative consequences on the workers performance. By setting the field of action available and allowing the workers to perform their procedures within the constraints, the workers health is likely to improve given that Karasek’s and Theorell’s theory of autonomy being the key concept to meet demands of workers health.

## **8.1 Conclusions of design for the new system**

In today’s system there are several workarounds in place and much of the operator’s time is taken by managing windows (bringing them up, resizing them, moving them and minimizing them), menus, messages and dialogue boxes. These are examples of unnecessary activities not directed to accomplishing tasks in a direct manner. The formative approach has shown new possibilities for performing tasks that used to place excessive cognitive strain on the operators. I have in the discussion chapter argued for solutions allowing the operators to interact primarily with the RAP window. Different suggestions on how to minimize the use of windows were discussed in section 7.2 and a summary is presented last in this section. The primary way to avoid this should be by

using tool bars in the edge of windows and for small screens using pre-defined views containing all relevant information needed when conducting tasks.

The abstraction hierarchy can be used top down to model, evaluate and re-think how a system's purpose is achieved. While the same hierarchy can be used bottom up, to evaluate how new technology can change and how the system will be affected, this ability was important during the evaluation of the new system. When certain functions were stripped it was important to see consequences throughout the whole system. One example of a change that affects the work within the system and was used to illustrate how the abstraction hierarchy could be used was; the removal of flight plan systems. Taking away flight plans affected only the identification process, whereas changing the working conditions and system interaction affected all functions carried out inside the system.

One important conclusion of the design for a new system is to provide operators with as much information as possible to determine the systems status. Although not all information can be presented at the same time, different kinds of information are important to handle unexpected situations. Identifying the information needed in unexpected situations is not a realistic goal; instead this study has strived to find additional sources of information not yet implemented in the Compact C2 and C2STRIC system and had the potential to support decisions of an operator.

### **Design suggestions**

- Toolbars
- Tabs
- Configurations unlocked with a license key/Button in menus
- Interaction tools adapted to new conditions.
- Screens adapted to the customers shape of country
- Make drop-down menus simpler with less submenus
- Replace top field with tabs fields
- When a specific radar stations window is opened tabs should be used for separating actions, settings and status
- Support for surveillance cycle
- Control settings of other centrals
- The bottom left field with system errors, information suited to ASO (not TSOP)

### **Areas for future research**

- Support for reference data not seen in the dark

- Further analysis of how identification process without flight plan can be conducted
- Evaluate if all support for optimization of radar stations is provided
- Exchanging of information of information in international warfare with Link 16
- Support reporting both air surveillance and more effective briefings

## 9 Reflections

The analysis of the air surveillance work was conducted with the CWA framework. In chapter 3 a short review was made of available paradigms, and the CWA framework was chosen to analyze the system with. The framework was explained and its potential for interface design was described together with general guidelines for interface design. The framework proved successful during the analysis of air surveillance work and additional analyses can use the framework and focus on different parts of the air surveillance or weapons control. In the WDA important functions were mapped and this forms a basis of where future analyses of the air surveillance should start. When analysing control tasks, a contextual activity analysis could prove useful. The CAT was left out of this thesis due to time constraints, but the CAT could give information of how different configurations of the Compact C2 systems depend on the context and the types of tasks occurring in different contexts. This could provide interface input to support different interfaces dependent on contexts. The omitted CAT has the effect that no design suggestions can be presented based on contextual factors.

The choice to only go in-depth with the identification function and do a quick analysis of the optimization process in the system, means that a great amount of the air surveillance work is still unexplored, more analyses is needed to make certain statements of how interface design should be designed to support all air surveillance work. More information and more valid information are likely to be gained with visits to an actual work place. Using air surveillance work in the factory should only be used to focus on how the C2STRIC performs.

The CWA frameworks main purpose is to give input to design and I believe that the analysis presented in this thesis can help when making design decisions. However, for an evaluation of an already implemented system, other analyses could be used to find areas that need to be improved. One of the techniques that could help finding those areas is the HTA analysis. Due to the user-centred design process, the operators really liked the system and operators had a really hard time coming up with complaints or suggestions. This was also one of the reasons why the CWA framework was used, to come up with new ideas. The CWA framework was useful for structuring the information, with more time the more experienced HMI team could be interviewed for design solutions that could further improve the system.

There is a difference in collecting information in the field in actual working conditions and seeing work in the Saab factory. This study found that steps to complete tasks were omitted by operators working at the Saab factory, an explanation of this could be that operators felt that there was no meaning completing certain tasks at the factory (e.g. write notes about malfunctioning radar stations). Field studies should (if possible) be used to gain a basic understanding of how certain tasks are conducted in the field. Analyses at the Saab factory should instead be used to record the behaviours and details of system interaction with the C2STRIC system.

During the field trip I expected to see normal working conditions. During the day I visited the central for air surveillance, a new way of working was being tested. The drawbacks of this were that the new way of working changed the operators' focus to different tasks compared to normal operation. The effect was that much of the data describing explanations and operator interactions

with the system could not be captured. The operators also spent too much focus on the track handling so very little else could be managed. The positive side of this was that I was able to collect a lot of data of working with the link 16 and difficulties of shared responsibility between centrals. The drawbacks were overcome with questions and did not affect the validity of the information.

I believe that working with the CWA for structuring information might be very valuable for the HMI-department, but also for the operators working with the system and participating in continuous meetings to discuss interface design. A way to collect data that was omitted due to time-constraints and difficulties obtaining interviews with operators was workshops. Much of the literature reviewed used workshops to obtain information of the system and brainstorm design solutions and I believe that would generate more validity to the data, as well as reliability. This way of working was used by Jansson et al. (2006) and testing this method instead of creating the SRK taxonomy could yield more information for design.

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# Appendix I: Glossary

Short	Explanation	Description
ADS	Abstraction Decomposition Space	For explanation see section 4.2
AH	Abstraction Hierarchy	For explanation see section 4.2
ASO	Air surveillance operator	Air surveillance operator working with the C2STRIC system. Responsible for monitoring, detect and identify tracks
ASOL	Air surveillance operator leader	Head of air surveillance operators, is responsible for air space monitoring and the link to JAL
ATC	Air Traffic Controller	Civilian aircraft coordinator
Battalion	a unit usually consisting of two or more companies and a headquarter	
C2STRIC	the system	
CAT	Contextual Activity Template	For explanation see section 4.2
CAT-DL	Contextual Activity Template vs. Decision Ladder	For explanation see section 4.2
CFSL	Head of fighter controllers	Leads FSL and are cooperating with civilian aircraft traffic controllers
COMOFF	Head of communication	
Company	a small unit consisting of two or three platoons	
ConTA	Control Task Analysis	What activities and tasks emanating from the system's purpose needs to be identified. Knowledge states and cognition (information processing) for these tasks are analyzed. This phase answer the question what.
CWA	Cognitive Work Analysis	Is described in Chapter 4. This analysis key concept is behaviour shaping constraints and this single framework integrates different models; a work domain, control tasks, strategy analysis, SOCA and WCA. This analysis answers the question why.
DH	Decomposition Hierarchy	For explanation see section 4.2
DL	Decision Ladder	For explanation see section 4.2
FD	Flow Diagram	For explanation see section 4.2
FSL	Fighter controller	Leads the fighter pilot towards the target through radio or data.
HTA	Hierarchical Task Analysis	For explanation see section 4.2
IFF	Identify Friend or Foe	This is an interrogation method for planes. Radar stations can send a signal asking the aircraft to identify themselves as friends. A negative response cannot positively identify the plane as an enemy. It also measures the bearing and range between the aircraft and station.
ILED/IDO1	Identification officer 1	Is responsible for identification of all tracked aircrafts
INCFSL	Incident preparedness air fight leader	Leads emergency response aircrafts after decision from JAL

JAL	Fighter leader	Decides about action with emergency response aircrafts
LE	Management system (equipped with the STRIC system)	
MRO	Multi role officer	Is a combination of MT1 and IDO1
MT1	Master tracker 1	Is responsible to track all aircrafts in their area.
Platoon	a unit which is a subdivision of a company, usually have a manpower ranging between 26 to 55	
PSR	Primary Surveillance Radar	Sends a lot of energy into the air and is not dependant on aircraft equipment.
RADARC	Radar controller	
raled	Head of Radio	
RAP	recognized air picture	A compiled description of what is happening in the air space
SA	Situation Awareness	
SOCA	Social organization and cooperation analysis	Identify who should perform a control task, or if the task can be allocated among a team of actors. Answer the question by whom.
SSR	Secondary Surveillance Radar	Sends radio signal to aircraft asking where and who it is and gets a response-signal if aircraft has working transponder.
StA	Strategies Analysis	This phase should as the name states identify all strategies used to solve a task and answer the question how.
StriC	Units equipped with the STRIC system	
sysadm	System administrator	
WCA	Worker Competencies Analysis	This analysis is based on the skill- , rule- and knowledge-based behaviour. Through the different behaviours it identifies competencies and techniques. And answers the question by what means.
	<b>Word Definitions</b>	
Cognition	mental processes (e.g. remembering, thinking, attention and making decisions)	
Command	The authority to make decision	
Control	The direction of weapons system and supporting platforms for accomplishment of assigned missions.	
Link 16	A secure, jam resistant Tactical Data Link (TDL) used for sharing digital information between different C2 systems (both airborne, land based and seaborne)	
C2	Command and Control	What a commander uses when making decisions and monitoring the execution of orders to accomplish the assigned mission.
TDFE	Track Data Fusion Engine	A multi sensor tracker and correlation. It establishes one track for each spotted aircraft by fusing measurements from any mix of active and passive sensors together with tracks provided by other systems.
Rote	Two fighter planes flying as a unit.	
	<b>Aircraft Identities</b>	
Faker	A friendly track acting as hostile for exercise purposes	
Friend	track belonging to a declared friendly nation	

Hostile	A track belonging to a declared opposing party (nation, group, entity). The track proposes danger to friendly forces; the danger is assessed from behaviour or from information on its origin, nationality and characteristics.	
Joker	A friendly track identified as suspect for exercise purposes.	
Kilo	A friendly track of social interest; special mission etc.	
Neutral	A track that is not opposing, nor supporting forces.	
Pending	a track that has not yet been subjected to the identification process	
Suspect	A track potentially hostile because of its behaviour, nationality, origin or characteristics.	
Unknown	Track has been evaluated, but not identified.	
Zombie	A Suspect category-track, conforming to ATC-rules or following recognized traffic pattern.	

# Appendix II: Interview questions

## Övergripande Frågor Om C2 systemet

Kom ihåg följdfrågorna varför, hur, var & kan det göras annorlunda? Begränsningar kommer att komma fram om jag bara frågar varför de arbetar på det beskrivna sättet.

**Allmänt:** namn, position och arbetsuppgifter.

### Work domain (DH)

- Vilka delar ses som hela systemet? (Luft, Marint, stridsledning, mark, HQ)
- Vilken är den grävsta biten som användare ser hela systemet i? (luftbevakning?)
- *Vilket är det hela system som arbetet organiseras kring? (C2STRIC?)*
- Vad ser användaren som en del av systemet? (delar som operatör ser och använder)
- Vilken är den mest detaljerade nivån som operatörer ser systemet?
- Vilka är de olika nivåer av detalj som användare ser av systemet?
- Vilka är de delar som användare organiserar sig kring i systemet? (luftbevakningen? C2STRIC, luftrummet)

### Work domain (AH)

- Varifrån kommer flygplanerna?
  - Är de pålitliga, kan militära plan läggas till för att lura systemet?
- Finns det någon skillnad för hur systemet fungerar i krigstid vs. fredstid, hur, varför?
- Skulle det behövas något extra i systemet för en krigssituation? (t.ex. mer information, snabbare system, annan organisation (plattare, lättare att ta beslut)).

### AH 1 av 4: Funktionellt syfte

#### Work domain

- Vilket är huvudsyftet bakom ”luftbevakning”, varför finns det? (regeringsdirektiv?)
  - Vilka prioriteringar finns inom domänen (mellan olika huvudsyften)?
  - Vilka är målen för arbetet med C2STRIC?

- Påverkar systemet (C2STRIC, samlade funktionen) omgivningen? (som att civil flygledning slutat med plottar)
- Vilka behov i omgivningen löser systemet? (borde också stå i regeringens direktiv av vad luftbevakningen måste klara av, eller har FMV utvecklat en mer specificerad bild)

## Omgivningens begränsningar

- Hur påverkar externa faktorer (omgivningen) systemet (i sin helhet och C2STRIC)?\*
  - Vilka positiva värden ger omgivningen till systemet? Finns det t.ex. någon fördel/nackdel med att systemet ligger i just Sverige?
  - Vilka lagar och regleringar påverkar systemet? (vad fås och vad fås inte göras, t.ex. utseendemässigt får inte göra vadsomhelst, Nato papper, kravspecc)( Bestämmelser från regeringen).
  - Finns det sociala lagar och regler som påverkar systemet? (t.ex. opinioner hos befolkning som påverkar: Etik, moral, principer)
- Ur vilken population rekryteras vanligtvis operatörer, har urvalet förändrats med avskaffningen av värnplikt och hur påverkar detta vilka personer som är tillgängliga (t.ex. nytt åldersspann, vad för detta med sig för skillnader)?

## AH 2 av 4: Abstrakt funktion

### Processens (avsedda) kausala struktur

- Mäts systemets förmåga att uppnå sitt syfte? (övningar, tidsmässigt, prestandamässigt, belastningsmässigt)
- Används några kriterier för att avgöra systemets förmåga att hålla sig inom gränserna satta av externa restriktioner (kolla att systemet följer t.ex. lagar, pålitligheter begränsade av radar)?
- Vilka övergripande syften löser uppgifterna i systemet?
  - Hur mäts det huruvida detta uppnåtts?
    - Ska det gå fort, hur fort?
    - Klara en viss typ av belastning? Hur stor?
- Vilka prioriteter av uppgifter finns det inom systemet?
  - Vilka kriterier kan användas för att prioritera de uppgifter som bedöms vara viktigast?



- Vilka kriterier används sedan för att fördela material och människor till de olika uppgifterna inom systemet?
- Vilka resurser fördelas idag till de olika uppgifterna i systemet? (6 personer luftbevakning, 4 kollar, 1 TSOP , 1 radarövervakare)

### AH 3 av 4: Generella funktioner

- Vilka är de huvuduppgifter som ska klaras av? (typ, se plan, leda plan, försvara Sverige, undvika olyckor, kontakta flyg, skicka information, identifiera)
  - Vilka funktioner krävs för att uppfylla huvudsyftet för hela systemet?
  - Finns det andra funktioner i systemet som används mycket?
  - Vilka funktioner krävs för att systemet ska klara de yttre begränsningarna (som beskrevs tidigare\*)?
  - Vilka uppgifter genomförs med fysiska resurser (t.ex. radar, telefon) i systemet?

### AH 4 av 4: Fysisk form

Utseende och form hos komponenter och kopplingar (placering, slitage, storlek, kanske skärmar, radarstationer)

- Vilka fysiska objekt finns inom systemet, både det som skapats och naturliga komponenter?
- Vilka fysiska objekt eller resurser är nödvändiga för att processer och funktioner i systemet ska fungera?
  - Vilka komponenter eller resurser finns i förteckningen (namn, nummer, typer)?
  - Vilka egenskaper har det material som används (form, dimensioner, färg, intern configuration).
  - Hur ser topografin ut med avseende på objekt (var finns olika komponenter)?
- Vilka fysiska funktioner har komponenterna? (hur fungerar dessa, inställningar, konfigurerbara delar, typ vem som ska ringas?)
  - Vilka begränsningar har komponenterna?
  - Vilken funktionalitet krävs hos komponenter för att klara av de krav som ställs av miljön?

### Organisatorisk analys

- Hur är arbetet fördelat mellan olika team?
  - Vilka uppgifter har team, individer och avdelningar?
- Vilka kriterier används för fördelning?
  - Hur koordineras de fysiska resurserna (menas även radar, telefon, acs) mellan de olika uppgifterna?
- Vilken natur har organisationen? (hierarkisk, demokratisk, platt)
  - Vid en oväntad händelse eller kritisk situation, ändras strukturen?
- Hur ser informationskedjan ut för:
  - olika uppgifter?
  - Briefing, vad går igenom, när?
  - Överlämning, vilken information skickas vidare till nästa kille.
  - Skiftbyte, vad förmedlas, hur?
  - Väderrapport?

### Actor's resources and values

- Vilken formell träning har operatörer?
- Erfarenheter av ämnesområdet och arbetsdomänen?

### Intervju operatör

### Uppgiftsfrågor (operatörsinriktade)

### Allmänna frågor i uppgiftsanalys

- Kan du beskriva dina huvudsakliga arbetsuppgifter?
- Vilka är dina prioriteringar av arbetsuppgifter?
- Vilka är de viktigaste **funktionerna** som används mest?
- Vad händer om de externa delarna (hemsidor, appar) av informationsinhämtningen inte fungerar? (någon civil server sluta fungera, telefonledning välter)
- Vad begränsar dig i ditt arbete, vilka ramar kan du inte gå utanför (begränsningar t.ex. i för säkerhetsskäl, startar inte aggressiv trackning för hänsyn till andra operatörer)?
- Finns det några typer av misstag som en operatör inte får göra men ändå är möjliga?

- Kan det uppstå faror i systemet? (t.ex. felaktig identitet) Hur löses dessa problem?
- Mro: sitter alla med den rollen, eller har de fortfarande ILED OCH MÅLED.
  - Sker identifikation hos varje operatör?
- HUR Kryssmärks en störars position, automatiskt?
- Används bullseye för att diskutera positioner på kartan eller är det platsnamn?

### **Radarfrågor**

- Vilka fel kan inträffa på en radarstation?
  - Vad får felet för konsekvenser?
  - Hur upptäcks felet?
  - Hur åtgärdas problemet? Beror det på vilken typ av radar och var radarstationen är placerad?
  - För vilka fel på radarn skickas en varning ut?
  - Noteras denna av operatören och vidtar direkta åtgärder när hon ser denna?

### **Externa källor**

- När används lathundar?
- När används onlinehjälp?
- Vad kollar du efter med hjälp av Internetskrämen?
- Vad antecknas på whiteboard?
- Hur hanteras kommunikationspanelen (touchscreenen), görs den om ofta?
  - Läggas tefnr in? Hur skapas och hittas befintligt nummer?

### **Förslag**

- Hur skulle du vilja göra arbetet?
- Saknar du någon information ibland, besvärlig att leta fram?
- Vad gillar du mest med arbetet? Vad tycker du minst om?
- Hur (i vilket format) skulle du vilja få information (gäller även briefing, inte bara C2STRIC)?
- Fungerar systemet som du vill?

### **Actor's resources and values**

- Skulle du vilja öva mer på någon del inom C2STRIC?
- Vad tycker du är lätt och vad är svårt med arbetet i C2STRIC?
- Vem säger åt dig vad du ska göra, fördelar arbetet, hur fördelas det?

## För varje uppgift i uppgiftslistan: följdfrågor

Operatören ska genom frågorna förklara **när**, **hur**, **varför** han gör uppgiften

- Vilka "ques" (signaler) signalerar att du måste utföra en uppgift, vilka planeras i god tid och vilka följs kontinuerligt? (typ gult systemspår).
- Vilka fysiska verktyg använder du för att lösa uppgiften? (whiteboard, telefon, radio, radar, ACS)
- Vilka flikar och funktioner i C2STRIC används?

## Task analysis in decision making terms

- Vilka beslut tas?
- Vilken information krävs för varje beslut?
- Vilka källor är användbara för att samla in informationen?
- Kollar operatör på officiella regler, kunskap eller går på rutin (skicklighet)?
  - När går operatörer på "känsla"?
  - När fungerar det automatiskt, utan aktivt tänkande, en signal medför en åtgärd?

## Task analysis in terms of strategies that can be used

Denna kategori ska också appliceras när operatören går igenom en uppgift.

- Kan uppgiften utföras på olika sätt, beroende på situation?
- Vilka strategier föredrar du som operatör?
- Hur ofta byter du strategi?
  - Finns det faktorer som avgör om det är dags att byta strategi? (till exempel om du har tidsbrist, för hög minnesbelastning eller inte kan slutet på nuvarande förfaringssätt)
- Vilken typ av information (och funktioner) behövs beroende på strategi?
- Vilka informationskällor (inom systemet) föredrar du?

## Slutligen

- Hur bedömer du om genomförandet av en uppgift var lyckat genomförd?

## Uppgiftslista

### Identifikation

Hur snabbt måste ett ovanligt beteende upptäckas?

- Om ett plan lagts till som civilt flyg, vilka faktorer skulle kunna avslöja att detta inte stämmer? (Höjd, fart, svängar, flyger inom speciella områden, flyger inte på ”motorvägar”, kommer från neutrala militära flygbaser).
- Hur urskiljs militär verksamhet från flygverksamhet enl. normalbild (Bedöms fart, höjd, uppträdande och hur beter sig då egen och civil flygverksamhet?)
- Om ett plan satts som vän och har tillstånd att flyga över Sverige, vad letar operatörer efter som kan avslöja att denne flyger ovanligt?
- Om du skulle få en signal om misstänkt flygning, som avviker, hur skulle du vilja visa den?
- Hur avgör ni om en zombie uppträder som ett normalt linjejet?
- Hur tänker ni om ett plan ser ut att följa flygfyr istället för rapportpunkter?
- Vilken tidslucka brukar du ha på att unknown ska bli zombie
  - vad har beteckningen zombie för fördelar?
  - Brukar flyg tillåtas bli zombie?
- Hur fungerar den automatiska identifikationen?
- Hur gör en operatör om inte automatisk identifikation fungerar?
- Hur kan en färdplan läsas och förstås?
  - Hur behandlas inkommande färdplaner och hur regleras inställningar för automatisk identifiering?
  - Hur kopplas denna sedan mot ett track? (t.ex. Genom färdplan kunna se flygningens färdväg på kartan. Kunna associera, deassociera, ändra identitet, platform och folder, tömma och skapa ny färdplan, Tillståndspärm)
- Gå igenom steg för steg vilken information som behövs för att genomföra:
  - Unknown→Assumed friend
  - Unknown→Friend
  - Unknown→Neutral
  - Unknown→Suspect

- Unknown→Hostile
  - Unknown→ Faker
  - Unknown→Joker
  - Unknown→Kilo
  - Unknown→Traveller
  - Vad betyder de olika beteckningarna?
  - Vad händer efter att beteckningarna är satta? På kartan, läggs de in i någon kategori?
- Hur gör operatörer för att identifiera på ett korrekt sätt? (plattform, callsign och flygplanstyp)
  - Hur eftersöks ett okänt flygplan med hjälp av tillgängliga resurser (passlaget, böcker, interna, externa kontaktytor, Internet, m.m.)
  - Hur listar ni ut till vilken del av civil flygledning som ni ska ringa för att identifiera?
    - Vilket nummer i telefonlistor ska ringas?
    - Ger systemet någon guidning?
    - Skulle du vilja ha någon guidning av systemet?

## Systemuppgifter

1. Hur optimeras målföljningen i C2STRIC genom inställningar i **MST** (*multi sensor tracking*), **information global criteria** och **inställningar för Search Area**
2. Hur kan operatören välja in och koppla upp olika typer av radarstationer i C2STRIC? (måste operatören göra detta, eller görs det av kommunikationsansvarig?)
3. Hur görs korrekta inställningar för resp. radarstation med avseende på t.ex. (*Init, MST, Slow int, Coverage, ECM.*)
4. Hur gör operatören för att fjärrmanövrera PS870 (ta manöverrätt, stoppa, starta sändning, släppa manöverrätten)
5. Hur gör operatören för att fjärrmanövrera PS861 (*priomärka fg, sända med "extended range"*)
6. Hur hanteras *Detection Areas* i C2STRIC (*vad är områdets användningsområde och funktion*)
7. Hur hanteras flightplanfönstret för att manuellt identifiera i C2STRIC (*koppla upp, söka, associera, ICAO bolag*)

8. Hur tolkas en grundfärdplan och hur kan en grundf. skrivas in i flightplan)

## Driftsuppgifter

1. Hur gör du som operatör för att målupptäcka nya plottar/företag på PR-/SSR-underlag
  - a. När reagerar och agerar du på nya plottar, målspar, företag?
  - b. Är det någon skillnad att arbeta under låg & hög belastning?
2. När samverkar du med de övriga operatörerna i C2STRIC (*Rapportera till lbevlad, med hänsyn till belastning och prioritet i ärendet. Sprida given information vidare i passlaget. Vid behov kunna samverka med JAL, FSL, TSOP och sbled. Känna av belastningen hos övriga lbevop och vid behov stötta där det behövs.*)
  - a. Hur sker samverkan?
3. Hur arbetar en operatör för att:
  - a. Lyssna av taktikrummet (sparas informationen i pappersform, skrivs den ned på whiteboard)
  - b. Använda och tolka given information från t ex briefingar, externa kontaktytor, kollegor, m.m.)
4. Hur optimeras radarbilden? (inval av sensorer, översikt, )
5. Hur genomförs uppstart eller övertagande av målföljning från annat C2STRIC, enl. Lbevlad direktiv?
6. Hur kopplas externa objekt upp? (LS10, DBU607, datalänkar och ev. annat C2STRIC)

## Rapportering

### Rapportera till Lbevlad:

- **När rapporteras till Lbevlad, hur och varför?**

#### Exempel:

- Då kränkning av Sveriges territorium är nära förestående.
  - Okänt företag eller flygverksamhet utan tillstånd som befinner sig nära Sveriges territorium.
  - Utländsk militär flygverksamhet.
  - Utländskt statsluftfartyg med tillstånd till svenskt territorium.
  - Begränsningar. (sensorer, system, mm)
  - Övrigt som avviker från normalbilden eller kan vara av intresse.
- **Vart rapporterar Lbevlad (luftbevakningsledaren), när, hur och varför?**
    - Hur fungerar: IS UndSäk, krypterade sambandsmedel



# Appendix III: Scenarios

## Inledande frågor

Hur länge har operatören arbetat med systemet och vilka roller brukar han ha?

## Förberedelser

1. Ställ in alla fönster och visning så som du är van vid att det ser ut.
2. Börja med att sätta upp spaningsområde och optimera radarbilden med inval av olika sensorer. (*optimering av radarbild*)
  - a. Hur görs inställningar för resp. radarstation? (*t.ex. Init, MST, Slow int, Coverage, ECM.*)

## Radar

3. En radarstation har tappat förbindelsen, en annan gör att målspar visas dubbelt, en tredje visar inga plottar som går till befintliga företag som den ”borde” se, inga varningar visas. (*Vilka fel kan inträffa på en radarstation?*)
  - i. Kan fejkas med att ändra position på radar i inställningar
  - b. Hur upptäcks de olika problemen?
  - c. När ett problem har upptäckts hur agerar du som operatör?
  - d. Hur åtgärdas problemet? (*Beror det på vilken typ av radar och var radarstationen är placerad?*)
4. Du ser ett intressant mål och vill ”belysa” det extra mycket med en specifik radarstation. (*prioritera fg, sända med ”extended range”*)
  5. PS860 måste vara inlagda och se mål
6. Du vill ställa in frekvensen som en station roterar med och en sektor som inte radarstationen inte ska rapportera.
  7. Vilka inställningar är vanliga att göra, varför, när, hur görs dem?
8. Du tappar en station som övervakar ett område ensamt, hur går du tillväga om det inte går att åtgärda på 2 dagar?
  9. Märker du ut att något har hänt på kartan, tar du bort någon form av ring för stationen?
  10. Hur viktig är ringen runt stationen?
11. Om du är osäker på vilka områden som är aktiverade för radarstationer, kan du tända alla?

## ***Tracking***

**12.** Du sitter och målföljer, men tycker inte att STRIC är rätt inställt för att upptäcka nya tracks eller följa befintliga, du vill optimera målföljningen. *(Hur optimeras målföljningen i C2StriC genom inställningar i MST (multi sensor tracking), information global criteria och inställningar för Search Area)*

**13.** Hur gör du som operatör för att målupptäcka nya plottar/företag på PR-/SSR-underlag vid:

**14.** Manuell Tracking

**15.** Automatisk tracking

- i. När reagerar och agerar du på nya plottar?(är det via möster?)
- ii. När reagerar och agerar du på nya målspar? (låter det automatiskt bli företag?)
- iii. Finns det områden där du normalt förväntar dig nya målspar?
- iv. Är det någon skillnad att arbeta under låg & hög belastning?

**16.** Det dyker upp två olika tracks brevid varandra, ena är äkta, andra är falskt, töm det falska, tracksen flyger inom Sveriges luftrum, färdplan saknas.

**17.** SSR- kod finns

**18.** SSR-kod saknas

**19.** Ett plan utan SSR passerar ut ur Sveriges luftrum, vad händer? *(övervakas detta och är det skillnad mellan olika flygtyper?)*

**20.** Det dyker upp ett målspar som skulle kunna vara en kryssningsmissil, vad gör du?

**21.** Vad hjälper att identifiera ett sådant track?

**22.** Vilken information behövs för att fatta beslut?

**23.** Du får ett storkryss på skärmen, identifiera detta.

**24.** Vilken information behöver du ta fram för att kunna identifiera?

**25.** Du ansvarar för två (eller fler) olika sektorer, gör inställningar som låter dig ta hand om både norrland och sydvästra Sverige.

**26.** Används det snabba sättet för att byta vy?

**27.** Hur modifieras övervakningscykeln?

**28.** Hur svårt är det att hänga med, vilka funktioner sköts inte, t.ex. kontroll av radar?

## ***Identifikation***

**29.** Ett nytt målspar har tillräckligt med underlag för att registreras som ett företag och företaget ska identifieras.

30. Ett plan passerar över Estland in i internationellt luftrum över östersjön i riktning mot Sverige, hastigheten är 600 km/h och höjd 8000 meter. SSR finns och är kopplat till färdplan. *(var hittas den och är den kontrollerad?)*

31. Ett plan dyker upp i internationellt luftrum mitt ute i Östersjön och har riktning mot Sverige. SSR finns och är kopplat till färdplan beskriver *trafikflyg*, spåret har hastighet på 1000km/h och höjd 4000 meter.

32. Den specifika färdplanen finns *inte*. Planet passerar över Estland in i internationellt luftrum över östersjön i riktning mot Sverige, SSR finns, hastigheten är 600 km/h och höjd 8000 meter. *(använder du: passlaget, böcker, interna, externa kontaktytor, Internet, m.m.?) (Skriver du in färdplan, eller identifieras bara flyget? hur skrivs den in, även den som kommer via fax)*

33. Den specifika färdplanen finns *inte*, SSR finns. Planet Dyker upp i internationellt luftrum mitt ute i Östersjön och har riktning mot Sverige, hastigheten är 1000 km/h och höjd 3000 meter.

*Förklara hur du skulle gå tillväga för att identifiera följande klasser (med SSR/utan färdplan → utan SSR):*

34. Unknown→Assumed friend

35. Unknown→Friend

36. Unknown→Neutral

37. Unknown→Suspect

38. Unknown→Hostile

39. Unknown→Faker

40. Unknown→Joker

41. Unknown→Kilo

42. Unknown→Traveller

43. Det dyker upp tre olika företag som har riktning mot Gotland, inga färdplaner finns och planen ligger i internationellt luftrum.

44. *Hur prioriteras planen?*
45. *Hur lämnas företag över, hur sker kommunikationen?*
46. **Företagen i lägesbilden är identifierade, plötsligt upptäcks ett ovanligt beteende hos ett identifierat flyg, t.ex. att ett plan avviker från sin färdplan väldigt mycket**
47. *Vilka avanliga beteenden finns?*
48. *Kontrolleras det att planet är rätt identifierat mot underlaget?*
49. **Den automatiska identifikationen upphör plötsligt att fungera. Färdplaner finns.**
50. **Du saknar uppkoppling mot Eurocat och har därför inga färdplaner. Hur arbetar du utan färdplaner?**
51. *finns det fasta rutter i någon form av lista?*
52. *Förutbestämda koder som identifiering går på?*

### ***Interaktionsverktyg***

53. **Om du vill visa symboler och markörer på stric, hur gör du?**
54. *Kan du rita vektorer? Bullseyen?*
55. *Kan du multi-hooka företag och sedan vätta en ram runt som någon operatör kan ta hand om?*

### ***Kommunikation***

56. **Det krävs bättre radarövervakning inom ett visst område, ASC 890 behövs, försök att få den att patrullera i din sektor, gör vad som behövs för att planet ska kunna sända information till ditt STRIC.**
57. *Förändra ASCens uppdrag via länk 16?*
58. **Ta in information och skicka information vidare via Länk 16.**
59. *Finns det några problem med att sköta kommunikationen via länk 16?*
60. *När sköts kommunikationen via länk 16/ samarbete med norge? Hur fungerar det?*
61. **Ditt pass är klart, lämna över till en pågående operatör.**
62. *Dagstid, med mycket trafik och det är första passet för dagen.*
63. *Dagstid, incidentberedskap.*
64. *Dagstid, med mycket trafik och det är det tredje passet för dagen*
65. *Nattetid, lite trafik*
66. **Överlämna hela luftläget till en annan anläggning.**

# Appendix IV: Complete AH

