

# Generic Support for Decision-Making in Effects-Based Management of Operations

KLAS WALLENIOUS



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and Communication**

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Nada är en gemensam institution mellan  
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KLAS WALLENIOUS

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# Abstract

This thesis investigates computer-based support tools to facilitate decision-making in civilian and military operations. As flexibility is essential when preparing for unknown threats to society, this support has to be general. Further motivations for flexible and general solutions include reduced costs for technical development and training, as well as faster and better informed decision-making.

We use the term *Effects-Based Management of Operations* to denote the accomplishment of desired effects beyond traditional military goals by the deployment of all types of available capabilities. Supporting this work, *DISCCO* (Decision Support for Command and Control) is a set of network-based services including *Command Support*, helping commanders in the human, collaborative and continuous process of evolving, evaluating, and executing solutions to their tasks, *Decision Support*, improving the human process by integrating automatic and semi-automatic generation and evaluation of plans, and a *Common Situation Model*, capturing the hierarchical structure of the situation regarding own, allied, neutral, and hostile resources.

The use of the DISCCO has been investigated in three different applications: planning for establishing surveillance of an operation area, planning for NBC defense, and executing a riot control operation. Together, these studies indicate that DISCCO is applicable in many different classes of Effects-Based Management of Operations. Hence, this generic concept will contribute to the work of both the civilian and military defense in dealing with a broad range of current and future threats to the society.

**Keywords:** Command and Control, Management, Effects-Based Operations, Command Support, Decision Support, Data Fusion, Information Fusion, Situation Awareness, Network-Based Defense, Ontology.



# Sammanfattning

I denna avhandling undersöks datorbaserade verktyg för att stödja beslutsfattande i civila och militära operationer. För att förebereda sig gentemot ännu okända hot mot samhället är användningen av flexibla lösningar avgörande, varför dessa stödverktyg måste hållas generella. Andra fördelar med att utveckla flexibla och generella lösningar innefattar minskade kostnader för den tekniska utvecklingen av verktygen samt för utbildningen i att använda dem.

Vi använder begreppet *effektbaserad ledning av operationer* för att beskriva arbetet hos beslutsfattarna i att åstadkomma önskade effekter bortom traditionellt militära mål genom att utnyttja av alla olika typer av tillgängliga resurser. DISCCO (Decision Support for Command and Control) är en uppsättning nätverksbaserade tjänster som underlättar detta arbete. Dessa innefattar *ledningsstöd*, som hjälper beslutsfattarna i sitt mänskliga och samarbetsinriktade arbete att utveckla, värdera och genomföra lösningar på tilldelade uppgifter, *beslutsstöd* som förstärker det mänskliga beslutsfattandet genom automatisk eller halvautomatisk generering och värdering av planer, samt en *gemensam situationsmodell* som beskriver den hierarkiska strukturen hos egna, allierade, neutrala och fientliga aktörer.

Tre olika användningsfall för DISCCO har studerats, alla med anknytning till ett internationellt uppdrag för ett svenskt förband. Dessa innefattar övervakning av ett operationsområde, planering av NBC-skydd, samt genomförande av ett uppdrag att stävja upplopp under ett toppmöte. Tillsammans ger dessa studier belägg för att DISCCO kan användas vid många olika slag av effektbaserad ledning av operationer. Sålunda kommer detta generiska koncept att bidra till både det civila och det militära försvaret av samhället gentemot nuvarande och framtida hot.

**Nyckelord:** Command and Control, ledning, effektbaserade operationer, ledningsstöd, beslutsstöd, datafusion, informationsfusion, situationsuppfattning, nätverksbaserat försvar, ontologi.





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# **Chapter 1**

## **Introduction**

### **1.1 Background**

This thesis investigates and proposes computer-based support tools to facilitate decision-making in civilian and military operations. As flexibility is essential when preparing for both known and unknown threats to society, these tools need to be general. Unexpected disasters, terrorism, international crimes, and spread of diseases, are all examples of threats that have revealed the vulnerability of our technologically advanced society. Changes of the threats in the world since the end of the cold war have radically changed the work and the assigned tasks for the military and for civil authorities; domestic, as well as international. Civil security has become an essential part in the daily work for these authorities. The ongoing globalization of people, economics, and politics, requires that threats to democracy and to the safety of people need to be managed independently of national borders.

In consequence of this development, the role of the Swedish total defense has changed dramatically. The tasks assigned to the Swedish Armed Forces include defending the nation against armed aggression, asserting territorial integrity, contributing to peace and security in the world around us, and strengthening the Swedish society to deal with peacetime emergencies. The previous separation between civilian security, rescue operations and disaster's relief at one hand and military operations at the other becomes less clear. However not undisputed from a constitutional point of view, both civilian and military resources will be needed to protect people from criminal actions, terrorism, accidents and natural disasters both within and outside the country.

*A Revolution in Military Affairs* (RMA) is a label that has been used to indicate the large changes that are foreseen in leading modern armed forces around the world [Blaker, 1996]. This revolution will enforce completely new doctrines and organizations for warfare. New ways of running business in the commercial sector, exploiting the fast development of information technology, will influence these changes. The concepts of warfare leveraged by new technology are also described as *Network Centric Warfare* (NCW) [Alberts *et al.*, 1999]. The network centric view, as opposed to the traditional platform centric view, will imply that information obtained somewhere in the organization can be supplied to anyone who is authorized and connected to the network. This enables decentralized decision-making and a reduced number of levels in the management hierarchy. It will also be possible to quickly adapt to upcoming tasks by designing temporary battle units from available resources. All this will facilitate faster and more focused reactions to events in the battle-space.

One extensive effort in this direction is being made by the Swedish Armed Forces. Confronted by no current threats directed to its territory, the Swedish state is taking the opportunity to cut the defense budget by reducing its number of forces. In turn, a part of these savings are spent on developing the *Network-Based Defense*. By this approach, the evolution of methods, organization, personnel, and technology, goes hand in hand, involving all defense services, industry, and academic institutions. This development is performed in short cycles, in which experiments play a vital role [Nilsson, 2000], [Nilsson, 2003].

Today, there are large difficulties in sharing information between the technical systems belonging to different defense organizations. We argue that to increase the interoperability, a more general approach on how to support defense activities is needed, as most support systems are designed with specific work tasks in mind. The traditional bottom-up approach to system design has its place since there are so many different activities going on in the defense organization. There are, admittedly, large differences between for instance calculating missile trajectories, navigating battle-ships, and supplying thousands of people with food and other supplies. Still, there is much in common in the work of managing these various tasks. Making decisions on organization of resources, and their assignments to different tasks, is



something that takes place, irrespective of the actual kinds of resources and tasks.

We recognize that an effort is being made to understand *Command and Control* (C2) in more general terms, especially from the fields of Network Centric Warfare [Alberts *et al.*, 1999] and decision-making processes [Klein, 1989]. However, the key issue when describing C2 in generic terms is to disregard which kinds of tasks that are solved and which kinds of resources that are managed. In this perspective, “the Art of War” should be excluded from our notion of C2, just as “system’s design” is excluded from “project management” in the software development business. Thus, C2 becomes similar to management in any kind of organization. Hence, after proper configuration, the derived support tools will be applicable also outside the traditional military C2 domain.

Further emphasizing threats and means in new domains and the mix between military and civilian actions, the concept of *Effects-Based Operations* (EBO) denotes actions taken to achieve effects beyond traditionally military goals [Smith, 2002]. These actions, performed by different organizations and authorities, are to be synchronized to accomplish desired effects and to avoid unwanted effects in the societal or cognitive domains, as well as in the physical domain.

Much can be gained by identifying general principles from C2, management, and EBO, in this work denoted *Effects-Based Management of Operations*, and by designing a common support system exploiting these principles. As opposed to specific support systems for different tasks, a general support system can be used in different positions throughout the military and the civilian organization. Thus, we argue that there are three main reasons why the defense will benefit from the development of a common support system based on general principles:

- *Interoperability.* A common support system will greatly facilitate coordination and cooperation between units throughout different parts of the organization, and also between different organizations. To this end, the communication between commanders can be changed from platform centric message-based communication into a more efficient interaction with a true network centric data model.

- *Flexibility.* The use of flexible solutions is the key to meet the unknown threats of the future. Relying on general tools and methods rather than on specialized ones, one will be better prepared to solve new tasks. Also, a common support system will encourage the establishment of temporary organizations to further support flexibility.
- *Cost effectiveness.* Development efforts will be more cost effective since there will be a greater focus on software reuse. In addition, reuse of training and experiences in using the system would further reduce costs. Commanders will feel more comfortable about changing positions since they will be able to utilize previously acquired skills in using the common system.

Consequently, the present work describes a top-down approach to support systems for decision-making in the context of Effects-Based Management of Operations, as a complement to the prevailing bottom-up approaches. *DISCCO* (Decision Support for Command and Control) is a set of network-based services including *Command Support Tools* helping commanders in the human, cooperative and continuous process of evolving, evaluating, and executing solutions to their tasks. The command tools provide the means to formulate and visualize tasks, plans and assessments, but also the means to visualize changes on the dynamic design of organization regarding roles, mandates, and obligations. Also included in *DISCCO*, are *Decision Support Tools* that, based on AI and simulation techniques, improve the human process by integrating automatic and semi-automatic generation and evaluation of plans to maximize the outcome in terms of desired effects. The tools provided by *DISCCO* interact with a *Common Situation Model* capturing the hierarchical structure of the situation, including the dynamic organization and the goals of own, allied, neutral, and hostile resources. Thus, compared to systems supporting C2 that are in use today, *DISCCO* will provide a more comprehensive situation description.

*DISCCO* shows generic features since it is designed to support a decision-making process abstracted from the actual kinds and details of the tasks that are solved. Thus, it will be useful through all phases of the operation, through all command levels, and through all the different organizations and activities that are involved. Consequently,

the usage of DISCCO may be applicable for both civilian and military purposes.

## 1.2 Overview of the Thesis

The first part of this thesis will give a survey of different aspects that provide the theoretical basis for the work in designing the support tools. In Chapter 2, we will discuss the terms *C2*, *management* and *Effects-Based Operations* to explain the kind of work that is to be supported. We will also define a synthesis of these concepts, denoted *Effects-Based Management of Operations*. This work is described further by providing a classification of different cases, in terms of at which command level and in which typical environment it is performed, and also in terms of the amount of time available for the decision-making.

The overview continues in Chapter 3, by discussing how the future military organization will change from bureaucracy, to other, more flexible, forms. This change will have a strong impact on the design.

As the work of performing C2 is, from our point of view, a case of *decision-making*, we will dedicate Chapter 4 to this matter. We will then discuss the implications of different research areas that prescribe how decisions should be made, and describe how humans deal with decision-making in practice. To this end, the concepts of probability and feedback systems provide essential strategies in managing uncertainty. Also, different kinds of decision processes that are used by the military provide input to our work.

After these introductory chapters, the thesis deals with defining a framework for the support tools. Based on existing models of *Situation Awareness* and *Data Fusion*, different levels of information supporting situation awareness are defined in Chapter 5. In turn, these levels provide the basis for a classification of the different support tools, including *Command Support*, *Decision Support*, *Information Fusion*, and *Multi-Sensor Data Fusion*. Together these tools will help the users in maintaining the *Common Situation Model*, and thus sharing their Situation Awareness among each other.

Although the emphasis in DISCCO is on the higher levels of Situation Awareness, an example of Multi-Sensor Data Fusion, the

*Wide Area Situation Picture* (WASP), is provided in Chapter 6. This is an approach to share information on the physical level aiming to make use of different sources to provide a coherent model of targets in the air and on the sea.

To implement the Common Situation Model, there must be a structure of the information. Thus, an *ontology* provides a language by which a situation is described. Accordingly, Chapter 7 captures what was learnt in the introductory chapters by presenting an ontology of C2, represented by a model in the *UML* (Unified Modeling Language). To this end, a decision-making process is presented that is generic in the sense that it represents all the different decision-methods that were presented in Chapter 4. From this process, represented by *Use Cases*, the main entities of the information needed in the Common Situation Model can be derived. Consequently, the information is further modeled by introducing *Class Diagrams* that represent important classes and relations.

The realization of DISCCO, building on this ontology, is further presented in Chapter 8. To this end, different tools are exemplified by screen-shots from a prototype system. In this chapter, the Command Support is described as being constituted by different views by which it is possible to interact with the Common Situation Model, which in turn is made available over a network. The Decision Support, on the other hand, is described based on the different steps in the generic decision-making process.

To further concretize the concepts of DISCCO and to evaluate its applicability, three studies providing different examples of applications is presented in Chapter 9, all relating to the management of an international peace-keeping operation. The first case deals with how to support the work of a battalion commander in establishing surveillance of the Area of Responsibility. The second case deals with the preparation of the defense of the Swedish contribution to the operation against nuclear, biological and chemical threats (NBC). The last case deals with a riot control mission during a summit in one of the major cities in the region. Each of these examples belongs to a certain case of Effects-Based Management of Operations, according to the classification presented in Chapter 2. Thus, together they cover a broad spectrum of work, illustrating the versatility of the generic DISCCO concept.

Finally, the thesis is concluded in Chapter 10, by recapitulating the approach presented, and discussing to what extent different classes of C2 and Effects-Based Management can be supported. A roadmap, describing further work on DISCCO, is also presented.

## 1.3 Perspectives

The thesis aims at designing technical tools to support the social and mental decision-making process denoted Effects-Based Management of Operations or, alternatively, Command and Control (C2). This process is performed by, mainly, military personnel at different decision-levels in an organization. C2 is thus performed within a structure represented by the organization, which defines command chains, rules of conduct, assigned tasks, etc. The perspective is recursive and hierarchical, since the C2 process forms the structure in which it is performed at a lower level, by making decisions on the organization on a subordinated decision-level.

The commanders have *awareness* of the real world that is more or less accurate and relevant for the decision-making. Represented by mental models, the awareness is said to be internal to the commanders. Externalizing the awareness to the technical artifacts is hence equivalent with maintaining a model of the real world in, e.g., a database. The external model is formed by perceiving the real world by sensors and direct observations, which gives rise to data that is interpreted by commanders in interaction with automated tools. The information flows in both directions, since the commanders interpret the external model to form internal models, which in turn are used to update the external model.

One of the key issues is to define the structure of the external model. We take a conceptual and generic view of the C2 process and the entities that the commanders can be aware of. Hence, classes of concepts can be defined that are present in many different instances of C2. Thus, many other aspects of work that can be studied are disregarded, such as particular domain knowledge, leadership, emotions, and stress. However, we discuss some concepts that human subjects have problems dealing with, such as probability measures and maintaining many decision-alternatives.

We also consider how to support decisions that are *good* in some sense. To this end, we argue that Bayesian decision-theory is a sound approach to make decisions based on uncertain information. This approach allows us to make coherent calculations of the expected utility, based on subjective and uncertain assessments of entity states and predicted consequences of actions.

## 1.4 Scientific Contribution

This thesis is based on a number of previous publications in which the author has been involved. These publications have been posted to research communities mainly dealing with Data Fusion, Modeling and Simulation, and Command and Control. Thus, the presented work contributes to the crossroads between these areas.

Consequently, the scientific contribution can be listed according to the following sections.

### The Previous Thesis

A substantial part of the contents has also been presented in the author's licentiate thesis [Wallenius, 2004b]. This includes results mainly introduced in [Wallenius, 2000], [Wallenius, 2000a], [Bergman and Wallenius, 2001], [Arnborg, et. al., 2000], [Brynielsson and Wallenius, 2001], [Brynielsson and Wallenius, 2003], [Huang *et. al.*, 2003], [Wallenius, 2002], [Wallenius, 2003], and [Wallenius, 2004], encompassing the following items:

- The WASP approach, described in Chapter 6, was first presented in [Wallenius, 2000], and was further described in [Wallenius, 2000a] and [Bergman and Wallenius, 2001]
- The discussions on the network centric structure, as opposed to the platform centric view, the contents of the Common Situation Model, and also different measures of the quality of information, presented in Chapter 5, were all originally outlined in [Arnborg, *et. al.*, 2000] but they were also presented in [Wallenius, 2000], and [Wallenius, 2000a].

- The generic game platform, GECCO, described in Section 8.3, was first presented in [Brynielsson and Wallenius, 2001].
- The use of simulation, together with a preference function, to support a generic decision-making process, as described in Section 8.3, has been presented in [Brynielsson and Wallenius, 2003] and [Huang *et. al.*, 2003].
- The generic model of C2 representing the ontology for the Common Situation Model, as presented in Chapter 7, was first defined in [Wallenius, 2002]
- The DISCCO concept in Chapter 8, encompassing the Common Situation Model, the Command Support, and the Decision Support, was first outlined in [Wallenius, 2003], and was further developed in [Wallenius, 2004a].
- The framework that classifies tools according to the levels of Situation Awareness and Data Fusion, presented in 5.3, was first proposed in [Wallenius, 2004].

## News in this Thesis

New contributions in this thesis mainly include results presented in, essentially, [Wallenius, 2004a], [Wallenius, 2005], and [Suzić and Wallenius, 2005]. Consequently, the new parts are described mainly in Section 2.2, 2.3, and 8.3, as well as in Chapter 9, including the following items:

- The application of Effects-Based Operations, as discussed in Section 2.2 and 2.3, supported by Influence Diagrams and *probabars*, as discussed in Section 8.3, was introduced in [Wallenius, 2005] and in [Suzić and Wallenius, 2005].
- The use of agent-based Monte Carlo simulation to provide input to the Influence Diagrams, discussed in Section 8.3, was presented in [Suzić and Wallenius, 2005].
- The case study on establishing surveillance in Section 9.2 was presented in [Wallenius, 2003] and in [Wallenius, 2004a].

- The case study on NBC defense in Section 9.3 was presented in [Wallenius, 2005].
- The case study on Riot Control in Section 9.4 was introduced in [Suzić and Wallenius, 2005].



## Chapter 2

# Effects-Based Management of Operations

The claim that a general set of technical tools may be designed to support military and civilian commanders in their work needs to be supported by a definition of this work. In this chapter we investigate the concepts of *Command and Control*, from the military tradition, and *Management* from the civilian tradition that partly describe the work of commanders. We also study the concept of *Effects-Based Operations*, which, related to Command and Control, further emphasizes the desired effects of actions in different domains. Finally, we denote the concept of *Effects-Based Management of Operations* as a synthesis of these concepts, dealing with both civilian and military means to achieve desired effects.

To further describe this concept, different classes of decision-makers are proposed and a tentative work process is suggested, before a final definition is given. The hypothesis throughout the thesis is that this kind of work shows large similarities between different classes of decision-makers, and that it can be facilitated by generic tools.

To provide evidence for the usefulness of Effects-Based Management of Operations, and to give a more concrete description, some instances of this concept will be further described in Chapter 9.

## 2.1 C2 and Management

*Command and Control*, C2, appears to be the term that best corresponds to the occupation of commanders, although, according to Roman, there is no agreement on what C2 really means [Roman, 1996]. The

definition given by Coakley seems to be most broadly in use [Coakley, 1991]:

*In general terms, C2 is everything an executive uses in making decisions and seeing that they are carried out; it includes the authority accruing from his or her appointment to a position and involves people, information, procedures, equipment, and the executive's own mind.*

We need, however, a definition describing what the commanders do rather than what means they have. As the introduction of common and general tools should facilitate co-operation and co-ordination between different parts of the organization, we also make the reflection that C2 cannot have the individual perspective of a single executive making decisions, as indicated by the definition above. Instead we need more focus on C2 as something that is performed in a system of individuals. Thus, there ought to be a common way to describe the work of the thousands of commanders included in any nation-wide military organization.

Obviously this work has to do with how to effectively utilize resources to achieve something. The decision made by, e.g., the Swedish Parliament to obtain armed forces for protection of the country is an abstraction of the intent for something to happen in the physical world. The work of the next people in the chain, the Supreme Commander and his staff, is to break down decisions, further from the Parliament and the Government, and closer to the physical reality, but yet many subordinated commanders are needed to fully implement the intent of the Parliament.

It is also evident that no single individual can perform all this work. The capability of performing C2 is obviously limited by the cognitive capacity of the commanders. There have been several approaches to quantifying this capacity. Among these, [Yufik and Cunningham, 2001] see resource allocation as a combinatorial problem. On his hand, [Anthony, 1999] has found regularities regarding the number of subordinates on different command levels within the U.S. Forces, indicating that commanders are able to manage an equal amount of details.

Using the approach of *Work Domain Analysis* [Rasmussen, 1993], the organization can be seen from different *levels of abstraction*. The

Parliament and the Government deal with the functional purpose of the Armed Forces as an abstraction of all physical objects belonging to the organization. In turn, the Supreme Commander, being one of these physical objects, thinks of the sub-organizations by their functional purposes and not by their physical realizations. In fact, such a Work Domain Analysis of the Australian Defense Forces has been performed, proving the fruitfulness of this approach when modeling C2 [Chin *et al.*, 1999].

Changing the level of abstraction clearly is essential when managing resources. Thus, the problem has to be broken down, both in terms of what to achieve (the tasks), and in terms of who should achieve it (the resources). Consequently, we argue that the following definition is more suitable to describe the work of commanders:

*C2 is the act of fulfilling a task assigned to an organization in terms of designing, evaluating, establishing, and executing, a solution on a lower level of abstraction. Hence, a solution is constituted by its subtasks, and by a subordinated organization of available resources, to fulfill these subtasks.*

This definition is generic since it does not depend on the actual kind of tasks and resources that are involved. It also describes the work of the commanders in a recursive manner. Thus, the definition indicates that there is a common denominator between C2 on different command levels and that these command levels are connected by the relations between tasks and solutions.

*Management* is another concept that is highly relevant for describing the work of commanders, and should therefore be mentioned. One of the meanings of this term given [Merriam-Webster, 1998], is very close to our definition of C2:

*Judicious use of means to accomplish an end.*

Presumably ‘management’ by tradition is related to civilian businesses, while ‘C2’ stems from the military domain. We argue that, according to our generic and conceptual approach, there will actually be no difference between management and C2. Hence, managing projects in the computer industry will be similar to planning a military operation,

although there are huge differences between military and civilian work in many other aspects.

## 2.2 Effects-Based Operations

Recently recognized in the military domain, the concept of *Effects-Based Operations*, EBO, further describes the kind of work performed by commanders. The new threats to society after the cold war require different mind sets to deal with conflicts. EBO emphasizes actions taken to achieve effects beyond traditional military goals. These actions are performed to accomplish desired effects and to avoid unwanted effects in the societal or cognitive domains, as well as in the physical domain. Consequently, there is a major focus on how actions affect people's minds [Smith, 2002]:

*Effects-based operations are coordinated sets of actions directed at shaping the behavior of friends, foes, and neutrals in peace, crisis and war.*

Since the effects are expected to occur in different domains, there is a need to use non-military resources as well. Hence, the synchronization of actions performed by different organizations and authorities is emphasized by some sources, for example according to the following definition of EBO [USJFCOM, 2005]:

*A process for obtaining a desired strategic outcome or "effect" on the enemy, through the synergistic, multiplicative, and cumulative application of the full range of military and non-military capabilities at the tactical, operational, and strategic levels.*

Also, the analysis of the extent to which effects are expected to occur plays an essential part in prevailing EBO concepts. Accordingly, there is an emphasis on the *mechanisms* describing the causal relationships between actions and achieved effects. Several previous authors have discussed methods to perform such analysis for EBO planning.

The example in Figure 2.1 illustrates such an approach, where different means to achieve the desired strategic effect, in this case the enemy's withdrawal, are considered. To this end, a mix of subordinated effects is suggested that together are expected to

facilitate withdrawal. Equally important is that subordinated effects that are likely to inhibit the desired end effect are part of the analysis [Wagenhals *et. al.*, 2003].

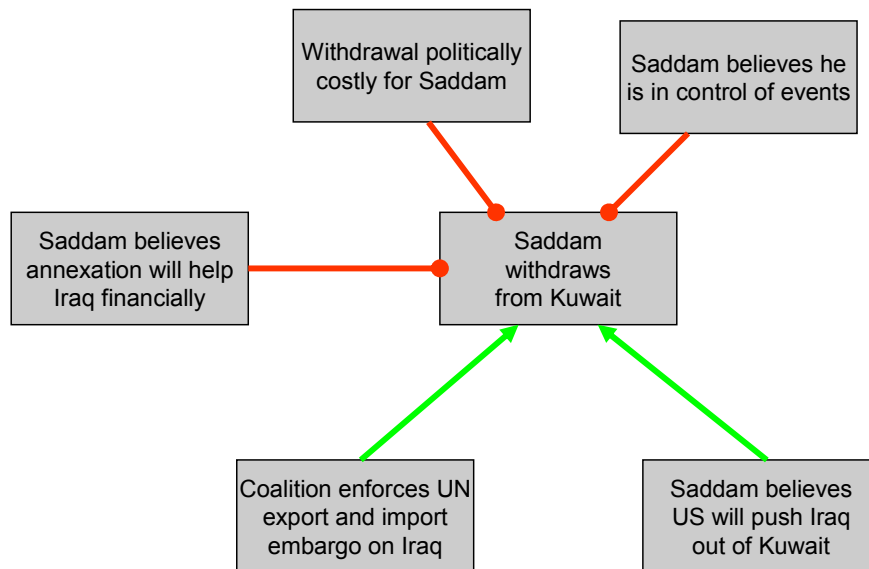


Figure 2.1. An effects-based analysis of different means to achieve a desired effect [Wagenhals *et. al.*, 2003].

In turn, different means are considered to achieve the facilitating, and to reduce the inhibiting, subordinated effects. The example in Figure 2.2 illustrates such a hierarchy of effects by suggesting how means to achieve a desired effect at one command level become desired effects at a subordinated level. Also, this example shows how effects in different domains, in this case diplomacy and intelligence, work together to achieve the common desired end effect [Duczynski, 2004].

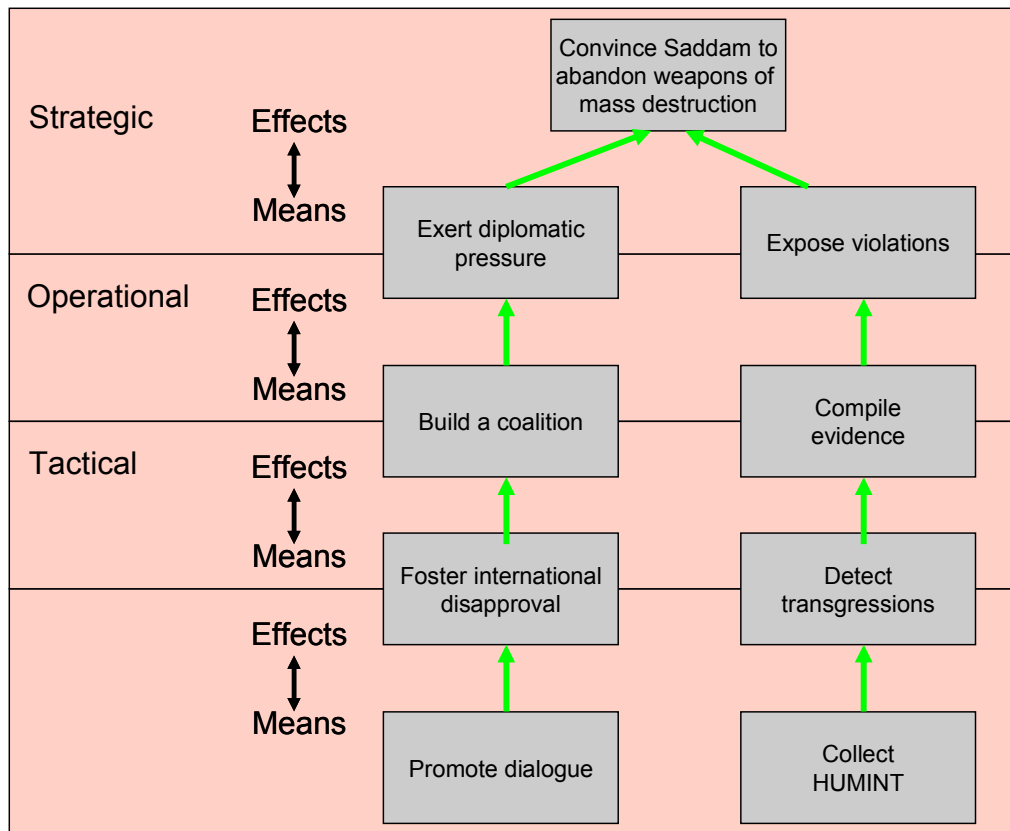


Figure 2.2. Chains of effects on different command levels in different domains contribute to the achievement of the overall goal. From [Duczynski, 2004].

## 2.3 A Synthesis: Effects-Based Management of Operations

The obvious similarities between C2 in the military domain, and management in the civilian domain, are very important. This is especially the case when developing support for interaction between military and civilian organizations in dealing with peace enforcement, terrorism control, disaster relief and human support. The ideas behind effects-based approaches, utilizing any capabilities to achieve strategic effects, further encourage the need for a common view between military and civilian approaches to what we denote *Effects-Based Management of Operations*.

In this work, actions performed by units belonging to different authorities, such as the police or the military, need to be carefully synchronized to achieve desired effects. Thus, commanders on different command levels and in different domains need to collaborate, despite of the fact that they work in different kinds of environment and have different amounts of time available for making decisions.

To illustrate the similarities and the differences between different instances of management of operations, a rough classification based on the timeframe of the work, and the typical environment in which it is performed, is suggested in Figure 2.3 and Figure 2.4.

In the civilian case, depicted in Figure 2.3, long term planning is performed on all authority levels, with rather long decision-cycles available. To reduce, or avoid, the negative effects of future crises, preventive planning is performed to analyze risks and threats to society and to design predefined plans on how to deal with different scenarios. Also, preparation should include how to monitor for negative effects, in order to quickly activate a crisis organization when needed. This kind of work is normally performed in a normal office environment.

Once an upcoming crisis is indicated, also depicted in Figure 2.3, the predefined plans are assessed in order to find the one that is most apt to reduce negative effects. The selected plan is continuously adapted to the unfolding situation and executed until the desired end state is achieved. During this phase, the time available for making decisions immediately shrinks among all authorities involved in the crisis. The shorter time available and the need for synchronization of actions trigger the requirement for dedicated meeting rooms in which interaction and decision-making may be performed much more effectively. On the lowest level, local authorities host resources such as police and rescue services that have people who are working out in the field, having even shorter time available to make decisions.

Management of a military conflict should follow a similar progress, also with time perspectives that differ between preparation and execution of an operation. Hence, Figure 2.4 roughly indicates timeframes and environments for different command levels during the execution phase of an operation. Note that similar classes of

decision-making can be applied both for the civilian and the military cases. Again, this similarity is the main premise throughout this thesis. The hypothesis is that all commanders involved in Effects-Based Management of Operations follow a similar pattern process roughly consisting of the following elements (see Figure 2.5):

- *Planning* and making decisions on own operations to achieve positive effects and avoid negative effects.
- *Analysis* of causal relationships between effects and operations.
- *Executing* operations to achieve and avoid effects
- *Monitoring* negative and positive effects of disasters, hostile actions and own operations.
- *Communicate and Coordinate* requests and predictions to other decision-levels and decision-makers.

Finally, we give a definition of this work by extending the definition of C2 in Section 2.1. Hence, the concept of ‘effects’ is added to the previous emphasis on change of abstraction:

*Effects-Based Management of Operations is the act of achieving effects according to a task assigned to an organization, in terms of planning, analyzing, executing and monitoring an operation. Hence, an operation is constituted by subordinated tasks to achieve effects on a lower level of abstraction, and by a subordinated organization of available resources to fulfill these subtasks.*

This is the most accurate definition of the work we aim at facilitating with support tools. We will however use the acronym ‘C2’ along with ‘Effects-Based Management of Operations’, meaning the same thing, throughout the thesis.



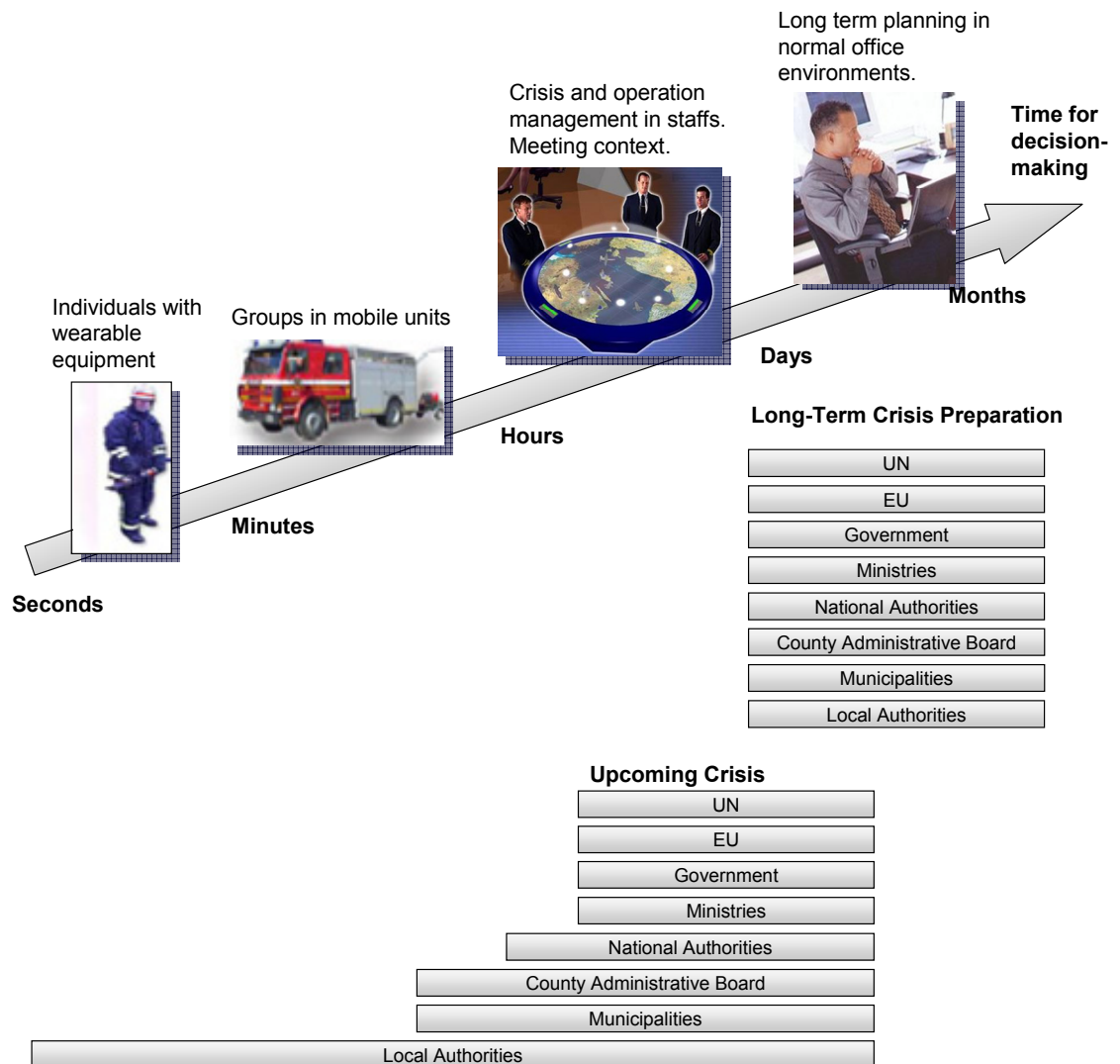


Figure 2.3. Suggested classes of decision-making in management of civilian crisis operations.

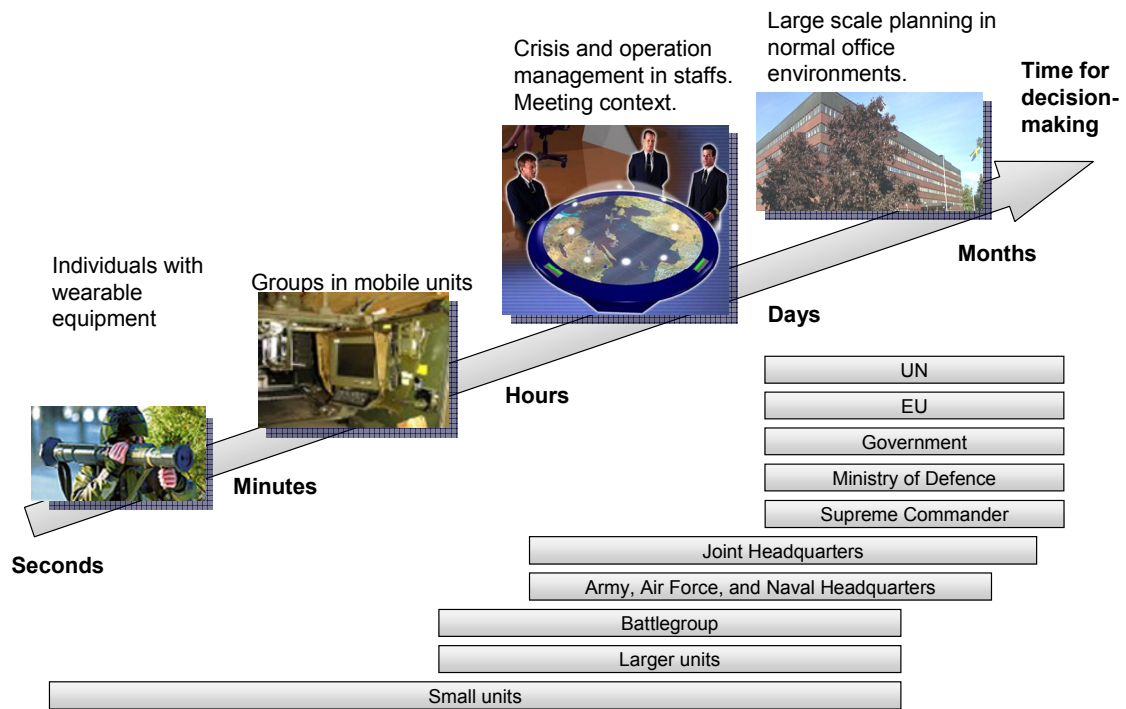


Figure 2.4. Suggested classes of decision-making in management of military operations.

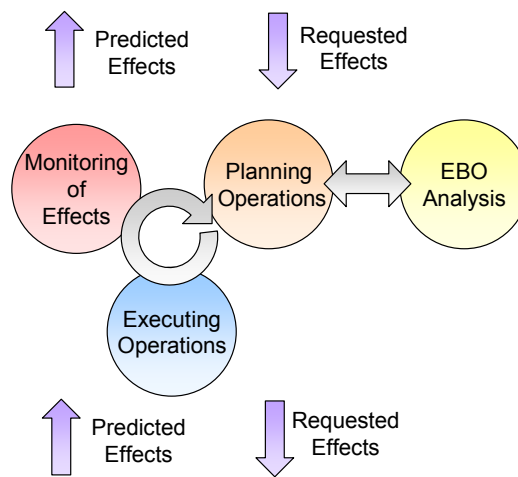


Figure 2.5. A tentative process describing Effects-Based Management of Operations.

## Chapter 3

# Organization

The organization plays a vital role in how to make decisions with a large number of people involved, as is the case when managing operations. The traditional picture of the military organization shows a rigid tree structure in which every organization unit has one and only one parent unit. Also, there are formal rules on who is allowed, and obliged, to share information and to make decisions. In this chapter we will discuss how this picture will change in the future by the need for more informal and flexible organizations.

### 3.1 Bureaucracy versus a Free Market

In the 1920's, the sociologist Max Weber defined the ideal-type *bureaucracy* as something that agrees with the image of the military organization. According to Weber, a bureaucracy is an organization that is rationally designed to achieve goals, and that has the following characteristics [Elwell, 1996]:

- Hierarchy of authority
- Impersonality
- Written rules of conduct
- Promotion based on achievement
- Division of labor by specialization
- Efficiency

According to the discussion in the previous chapter, a commander acts on an order from his superior commander, and in turn, issues

orders to the subordinated forces. Hence, it seems that C2 is performed just in accordance with the bureaucratic principles.

Some researchers, such as for instance Dahlbom, however maintain that traditionally hierarchical organizations will soon be outdated [Dahlbom, 2000]. Young people currently growing up with new information technology will get used to setting up their own goals in a free market of possibilities to act. According to Dahlbom, local agreements on what to perform will be the norm, and not receiving orders from the superior commander. Personal values rather than legal authority will hence guide novel organizations according to this view.

Consequently, it is often argued that the organization can be removed completely, seemingly making the notion of C2 obsolete. Still, at least someone has to find out how to set and fulfill goals. An individual making decisions on his own actions, rather than on the actions of the subordinated, is thus performing C2 in a wider sense. As long as we believe that the owner of resources has the slightest possibility to decide how to utilize them to achieve something, the work of C2 to change the level of abstraction will be necessary. Nevertheless it must be acknowledged that the current trends will highly affect the view of what C2 is. We will thus investigate what might be denoted the *networked organization* from two perspectives.

## 3.2 Tacit and Informal Organizations

The first perspective that can be taken on networked organizations regards relaxation of formal regulations. As the collection of decisions concerning tasks and subordinations represent the will of the commanders, it can be seen as a prescriptive model of what should happen. However, as is the case with all models, it cannot represent the real world in all aspects. Any system that assumes that the model is equal to the real world can be expected to be highly ineffective. [Sachs, 1995] emphasizes this by acknowledging the activity-oriented tacit view of work as being equally important as the organizational explicit view. The former, Sachs says, takes into account informal political systems, networks of contacts, know-how and work practices, while the latter describes work in the sense of tasks, procedures, and

position in hierarchy. She thus maintains that a system that does not account for the tacit view will tend to discourage co-operation and learning and provide the need for working around problems that do not fit the model.

To this end, it must be acknowledged that C2 is something that may be performed irrespectively of whether decisions are made according to formal rules or not. Certainly the authority to make decisions may be accruing from the position of a commander, as in Coakley's definition of C2, but on the other hand one can think of cases when decisions are made completely without such authority. Thus, we argue that a decision in the general case is a result of mutual negotiations between individuals. The outcome of such negotiations will depend on the balance between the authorities of superior, subordinated, as well as peer, commanders. In turn, this balance depends on doctrine, culture, informal leadership, available communication channels, and other circumstances. It must also be noted that decisions on tasks and subordinations can be explicitly captured in orders and other documentation, but they can just as well be represented as tacit understandings between individuals.

### 3.3 Virtual Organizations

The second perspective of changes implied by the new technology regards the requirement for dynamic and multiple organizations (which may still be very formal). As shown by [Alberts *et al.*, 1999], the effect of weapon platforms, such as ships, tanks, and aircraft, can be increased tremendously when carefully synchronized during a mission. Hence, it should be possible to quickly put resources together to accomplish a particular task. When the task is over, the resources can be released for other tasks. This, according to [Alberts *et al.*, 1999], can be solved by *virtual organizations*. [Borchert and Jones, 1999], for instance, investigate an organization of weapons and sensors that may be different from the organization that controls the platforms. Also, these multiple organization trees change during the different phases of the mission.

Collaborative Planning is another example of the required flexibility. It is increasingly common that the military staffs have to plan for tasks

that they were not prepared for, e.g., crisis planning. The division of expertise in different sections of the staff may thus not be sufficient for the new situations at hand. Temporary cells with expertise from different sections are thus established to plan for these unexpected tasks [McKearney, 2000]. These temporary groups can, again, be regarded as alternative organizations.

A third example of flexible organizations regards the organization of the Swedish Armed Forces, which expects to increase utility from the limited future resources by the capability to assemble battle units on demand. By this possibility, the organization can rapidly be adapted to changes in the threat picture. Consequently, the Swedish Armed Forces have chains of command for missions that differ from the chains of command for other issues [Swedish Armed Forces, 2001].

All these examples show the importance of not assuming anything about a static organization in our notion of C2. To this end, the definition of C2, which we gave in the previous chapter, emphasizes the fact that the organization is something that is designed dynamically as a part of solving a task. Also, a resource may be subordinated on a long-term basis to one organization and, concurrently, to one or several others during shorter periods.

## Chapter 4

# Decision-Making

According to our definition, C2 can be regarded as an act of decision-making in a system of decision-makers dealing with different levels of abstraction. To get a deeper understanding of C2, it thus would be of interest to consider different research fields concerned with decision-making. According to [Kleindorfer *et. al.*, 1993], the many theories on decision-making can be classified as being either *prescriptive*, in that they prescribe what decisions should be made or *descriptive* in that they describe how decisions are made in practice.

One of the oldest surviving examples of prescriptive recipes for decision-making can be found in the Nichomachean Ethics of Aristotle [Hutchinson, 1995]. In modern language, his advice to a young Greek gentleman for deciding his course of life is to understand what he would regard as a good life, investigate the probable consequences of the alternatives, and choose the one that most likely leads to a good life. While the advice must be considered simplistic from a modern scientific point of view, the gist of the advice is what is taught today in *Decision Theory*: Among a set of actions, choose one that maximizes expected utility [Jaynes, 2003] [Berger 1985] [Raiffa, 1968]. In *Game Theory*, originally a descriptive theory, there are two or more parties who, interdependently, aim to maximize their own utility [Myerson, 1991] [Osborne and Rubinstein, 1994]. It remains to find a way to compute this expected utility in a concrete given situation. Much of applied decision theory is concerned with finding reasonable and feasible ways to do this. In some cases, particularly in artificial games of chance and some types of business decisions, there are accepted procedures by which decisions can be analyzed using probability and utility and under constraints of time and effort [Lichtenberg, 2000]. In other areas, no such consensus is present and it is often questioned whether probability and utility are the right tools.

The descriptive theories, on the other hand, study the psychological or social processes of decision-making. In *Cognitive Psychology* [Montgomery, 1992], it has been shown that the decision process of an individual follows a set of rather simple principles to compare different decision alternatives. One example of such principles is the conjunctive rule, which states that decision alternatives not complying with all requirements should be rejected. This rule, however, is derived from studies of situations where explicit decision alternatives are presented to the individuals. In contrast, psychologists in the discipline of *Naturalistic Decision-Making* [Klein, 1989] have shown that decision-making in natural settings is a process tightly connected to the process of understanding the problem. Once the problem is fully understood, the decision-maker also has the solution for it.

The conclusion to us is that tools to support C2 should assist the commanders to understand the problem and to make well-founded decisions according to the prescriptive theories. The tools should, at the same time, make the users feel comfortable in their work by supporting natural decision processes according to the descriptive sciences. In trying to combine these, we will now go a little bit deeper by starting with the concepts of probability and expected utility that are essential to the prescriptive decision theory. This will be followed by an investigation of the roles of feedback and time in decision-making. Finally, we will look into some prescriptive, as well as descriptive, models on how decision-making is pursued within organizations of, e.g., military commanders.

## **4.1 Probability and Expected Utility**

### **Probabilities in Real Life**

The definition of probabilities in real life situations, as opposed to the mathematical probability concept, has caused one of the longest controversies in 20th century science. Several researchers are pursuing ways of decision-making uncoupled from probability, with the motivation that probabilities do not exist or can simply not be determined. For an overview, see, e.g., [Walley, 1991].



On the other side in this controversy are the so-called Bayesians, who persist in using their version (the only version, they say) of subjective probability. Their main argument is that any numerical measure of uncertainty that is not equivalent to probability is inconsistent and may lead to gross and obvious errors if used indiscriminately. This is an interesting fundamental result first derived in parts by several independent researchers, see [Savage, 1954], [de Finetti, 1974] and [Cox, 1946], among others. These investigations have later been made more precise in terms of which assumptions are being made, and today it seems difficult to argue that some numerical measure different from probability is the right concept for describing real-life uncertainty [Arnborg and Sjödin, 2000]. The details of these investigations are rather complex and are not discussed here. Nevertheless, probability models for complex real-life situations are difficult to make precise in the same way as can be done for analysis of artificial games of chance where the probability concept enters crisply in assumptions of how, for example, a card deck has been shuffled.

In engineered systems, like trackers in weapons systems, it is usually possible to make probability models that are reasonable – if not exact. Uncertainty about error distributions can usually be approximated using results from experiments and simulations. Probability values can also be set, not with the aim to correspond to any “real” uncertainties, but simply to tune these systems. For example, entering a high probability for false radar detections will result in better performance at situations with severe weather conditions, but with a cost of less accurate tracking when the weather is better. Hence, operators may tune parameters until the performance of the system fulfils the requirements at certain test cases.

For C2 problems, like the probability that a particular unit can defeat an enemy unit, probabilities become even vaguer, and, hence, more controversial, since many very important factors are highly subjective. Such estimates must be based on the training and the mental state of the decision-maker. Deception measures used by the involved parties must also be taken into account. Since different assessors of probability models rely on past training and experience, it is inevitable that two highly competent experts in a domain can have different personal probability assessments.

## Bayesian Inference

Probability estimates are typically obtained in two steps. First, a general model is set up for a generic situation. Second, such a model contains parameters describing a particular instance of the situation, like the numbers and states of various units, and their intents. Such parameters must be assessed, and then the probabilities of various outcomes follow. Some parameters, like capabilities of own units, can be known and are in that case just plugged into the generic probability model. Others, like capabilities and intents of enemy units, must be inferred indirectly from variables that can be observed. By applying the formula given by Thomas Bayes in 1763, *Bayesian inference* admits using knowledge from new observations to update the probability distribution of an unknown parameter [Jaynes, 2003].

In cases where important variables are totally unidentifiable, one has to rely on prior variable distributions, typically leading to rather vague distributions that are difficult to act on. The importance of this possibility can be illustrated with the study presented by [Lindberg, 2003], aiming at predicting an impending full-scale attack on the own Navy. The preliminary assumption was that positions of enemy platforms would be important indicators. However, with modern long-range weapons and the enemy's need to achieve a surprise effect, it was found that these positions give little information. Instead, the qualitative political situation and hard evidence in form of electronic signatures before an attack must be used, and a deep analysis on alternative indicators must be performed.

The main challenge in C2 applications of Bayesian inference is to find a suitable family of models that is tractable computationally, and explainable as well as acceptable to users. Several research activities in C2 research aim at developing such model families. A model family that is often attractive to users and has reasonable computational properties is the family of Bayesian Networks (also known as graphical models) [Jensen, 2001] [Suzić, 2003] [Suzić, 2003a] [Runqvist, 2004].

## Extended Probability

Although any numerical measure of uncertainty is either inconsistent or equivalent to probability, there are fully consistent measures of uncertainty that are not numerical measures. One family of measures can be described using infinitesimal probabilities, which is one way to explain the family of non-monotone logics often used in AI research. An infinitesimal probability can be seen as a probability number that is smaller than any real number even if multiplied with a large number. One can thus see a set of infinitesimal probabilities as numbers of different magnitude, but without an absolute real valued scale.

Another family of measures is of more direct interest in our applications, and is based on the idea that a situation is described not by one probability model but by a family of probability models. Such a family can for example be the result of several experts with different backgrounds not being able to agree on a common model. It has also been argued as a robust way to handle tracking systems using complex sensors whose behavior in the field cannot easily be determined by experiments [Mahler, 2001]. When a family of models is accepted, each member model gives a different answer for the probability of a particular event. The measure of uncertainty given by this approach is thus a set of probabilities, usually reported as the interval from the lowest to the highest probability of the set.

When combined with utilities of outcomes, the expected utility of an action will also be an interval, and the recipe for selecting an action will be that an action should be chosen whose interval is not inferior to the interval of some other action, in the sense of being disjoint and with lower utility values.

Examples of methods in this category that are applicable to C2 applications include Dempster-Shafer theory [Shafer, 1976], and random set theory [Goodman *et. al.*, 1997]. We do not claim that all methods in these categories are exactly equivalent to using families of probability models, but some are.

## Ellsberg's Paradox and Prospect Theory

There are several indications in behavioral research stating that human decision makers do not obey simplistic utility maximization behavior

in experimental situations. Two schools of research in this area started, one with a result of [Ellsberg, 1961] and one with [Tversky and Khaneman, 1981]. Of course, it seems reasonable that an uneducated subject does not think deep enough to make rational decisions, but these experiments are often performed with very well educated subjects who are given a precise and simple description about their task. Thus, the results have indeed been used to criticize the mainstream highbrow line in decision science, which is to maximize a crisp utility in more and more complex but well-defined mathematical settings. We will now see a tentative reconciliation of these controversial observations.

In experiments performed by [Ellsberg, 1961], the participants are given decision situations where they are told that probabilities lie in certain given intervals, but are not given any clue on where in the intervals the probabilities lie. According to standard Bayesian reasoning, the subjects should have some subjective conviction on how they are placed in the intervals, e.g., uniformly, and then use the stated payoffs to compute expected utilities to decide alternatives. The paradox is that in general this is not done, which can be found out by investigating how the decisions depend on the stated payoffs. Apparently, subjects use the whole family of possible probability distributions to get an interval in the utility of each decision. They can also be classified into risk-seeking and risk-averse in the sense that they try to maximize the upper or lower utility interval endpoint. Some experiments also hint at the possibility that some subjects tend to be Bayesians, and indeed use the interval midpoints as their probability estimates [Smithson *et. al.*, 1999].

The prospect theory of [Tversky and Khaneman, 1981] was also developed by studying how subjects make decisions in simple experimental situations. They focus on how the decision problem is formulated, and they observed a definite dependence between decisions chosen and the way the problem was presented. As can be imagined, this is valuable in business sciences and particularly in promotion commercials. For anyone interested in pursuing traditional utility maximization, these results are mainly a warning that it is essential that decision alternatives are presented in fair, or at least thought-through, ways.

## Game-Theoretic Approaches

In the C2 domain, at least in the military case, there is an opponent that can be described with unobservable intents and also has an interest in deception. In ground operations, there are many different intents and judgments made by agents on both sides. Situations with several agents, each trying to maximize his expected utility, are analyzed in game theory. The full-information zero-sum game was given a simple and final solution by [Neumann and Morgenstern, 1953]. Such games have a rational solution where each party uses a randomized strategy, i.e., decides the alternative probabilistically (by flipping coins or using a random number). Already when the opponent's utility is not the opposite of the own utility, the complications abound. The concept of Nash equilibria is a tool to attack these games [Osborne and Rubinstein, 1994]. Finally, when agents are not sure about each other's information states and utility functions, the analysis of Bayesian Games is relevant.

Certainly, the assumptions behind Bayesian Game Theory are very relevant in the C2 domain, but the difficulties should not be underestimated. There are several important difficulties in applying Bayesian Game theory in naturally occurring situations. One is that the parameters of a game necessarily must be subtle and difficult to assess. Another is the complexity of the theory itself. In the Bayesian game situation, where probabilistic information is used, the mathematical complexities are significant. A fundamental result on the well-definedness of the Bayesian game situation was obtained by Selten, which is summarized by [Myerson, 1991].

There is very limited experience of actually applying reasoning about the other party's information in the C2 domain, despite the obvious conceptual relevance of the approach. Some preliminary studies are reported by the group of Gmytrasiewicz, where a discrete and simplified model of the recursive structure of the 'knowledge about knowledge' problem is developed [Gmytrasiewicz and Durfee, 2000]. They mainly address the problem of coordination of friendly agents based on observations giving clues about their states. In most C2 research efforts, one tries to model the intention of the enemy without recursive models. The enemy is then described as an agent that does not reflect on what our intentions may be, but as one

following doctrines and using plans obtained by training. This has been shown useful in some (still) simple situations [Suzić, 2003].

## **Expected Utility and Multiple Objectives**

Why should expected utility be used as a criterion for selecting the best action in a situation? The assumption behind the utility concept is that an individual can order the possible outcomes in order of preference and also grade them on a numerical scale. After having obtained these numerical grades, probabilities are used as mixing coefficients to find the expected utility. An action that leads to utility -1 or 1, each with probability 0.5 is thus equivalent to an action that leads to utility 0 with probability 1. It seems as if a risk-averse individual would prefer certain utility 0 before the risk of losing 1 unit. The answer to this problem is that utility like probability is a subjective concept, and a risk-averse person would adjust his utility scale accordingly. This answer also answers the insurance paradox: Since the insurance company must make expected monetary profit, the insurance holder must make expected monetary loss. Why should anyone take insurance under these circumstances? The answer is again that the insurance company has a different utility grading based essentially on monetary expectation whereas the insurance taker values a large economic loss much more seriously than the certain loss of the insurance cost. This difference in personal utility measure is what makes insurance transactions (and also all other transactions according to some theories of economics) possible. An eloquent explanation of these phenomena can be found in [Jaynes, 2003].

The realization that utility is subjective means that our system cannot easily compute the utility of an outcome. The utility is typically dependent on variables like goal achievement, losses of own and enemy resources, and damage to third parties like infrastructure and civilian population. The contribution of each such essentially quantitative variable to utility will depend on the total situation in the conflict and even varies from one operation to the next. This problem is attacked in decision theory by *Multiple-Objective Optimization*.

The problem with this approach is that the multiple objectives may be of very different quality, and hence it is very difficult to an individual to compare these to each other. Descriptive models on how people

deal with this have been developed within the field of Cognitive Psychology. Accordingly, [Montgomery, 1992] lists the following decision rules:

- *The dominance rule:* Select the strategy that is equal to or better than all alternative strategies in all attributes.
- *The conjunctive rule:* Select the strategy that is better than a threshold value in each attribute.
- *The disjunctive rule:* Select the strategy that is better than a threshold value in only one attribute.
- *The lexicographic rule:* Select the strategy that is better than the alternatives in the most important attribute.
- *Choice of the alternative with the most attractive value of a single attribute:* Select the strategy that has the highest utility in a single attribute compared to all other strategies and attributes.
- *The addition rule:* Select the strategy that yields the highest weighted sum of utilities in all attributes.

The subjective and context dependent character of utilities makes it necessary to be able to manipulate utility scales interactively and rapidly. Methods for this should comply with rational decision theory in that total expected utility is maximized, and yet be possible to deal with, for instance by complying to the decision rules above, as long as they do not contradict. [Brynielsson and Wallenius, 2003] has developed the concept on how to represent and compare expected utilities in different attributes by a *Preference Function*. The use of this function will be further discussed in Section 8.3.

## 4.2 On Feedback and Time

### Critical Rationalism: Conjecture and Refutation

Making rational decisions in accordance with decision theory requires that the consequences of the potential decisions can be assessed. Hence, based on previously obtained knowledge or observations, the

decision-maker is to make a prediction of the future outcome, given that a potential decision is made. Such prediction, as we see it, is analogous to the Aristotle's definition of *induction*, i.e., inferring a general claim from its number of instances [Smith, 1995]:

*Socrates has two legs.*  
*Plato has two legs.*  
*Aristotle has two legs.*  
*Therefore all humans have two legs.*

Reacting to the ideas of RMA, [Giffin, 2002] argues that it is futile to predict the outcome of, e.g., a battle-plan. Since induction logically is an impossible method, Giffin maintains, the result of the prediction cannot be proved. Instead he suggests the application of Carl Popper's scientific method of *Critical Rationalism*: since a hypothesis can never be proved, one should instead try to refute it. The iterative process of conjecturing and refuting hypotheses will thus result in successively better knowledge of how to solve the task. If a solution is a hypothesis on how a task may be accomplished, C2 should consequently be performed by trying solutions and being prepared to change them according to the observed results, rather than by designing detailed battle plans and think that they will work.

We argue, however, that the commander indeed has to rely on induction to assess the potential solutions to the task. At a given point in time, the commander must decide how to act upon what he *believes*, given available information. The decision cannot be avoided since the decision not to act is also based on beliefs. This perfectly conforms to rational decision-making under uncertainty, according to the previous discussion on Bayesian inference. Predicting future consequences is thus based on knowledge representing previous experiences personally gained by the decision-maker or by others. The larger amount of experiences relevant to the problem at hand, the more reliable the prediction will be. If this knowledge is seen as a set of hypotheses, or models, of the real world, then the conjecture-and-refutation loop is one way of improving this knowledge. Hence, it is of great importance that the refutation really is performed under realistic conditions by relevant training, exercises, and tests of methods.



When it comes to military decision-making, knowledge is mainly based on experiences from previous conflicts, and in many cases from training under conditions that can only aim at being realistic. Although induction is necessary and not impossible, it may prove very difficult to make predictions about the future, just as Giffin argues. Experiences gained in training sessions, and by participation in real conflicts, may prove inaccurate in the next conflict, because of the inevitable development of technology and methodology of all parties. Consequently, the planning of military operations must allow for continuous reconsideration of the decisions that are made. Plans should be adapted according to new information as time passes. Also before and after the execution of a decision, this conjecture and refutation loop needs to take place. During the planning phase a tentative plan needs to be successively improved by intuitive or analytical assessment based on the planning methods that are applied. After the execution it must be assessed whether the task actually has been fulfilled or whether further action needs to be taken.

Simulation technology may be used to support the projection, as will be discussed in Section 8.3. However, simulation models also represent knowledge with a limited accuracy, and should thus be applied carefully.

## **Cybernetics and Control Theory**

The need for continuous reconsideration of decision alternatives in the C2 domain is usually not emphasized in decision theory, as discussed in Section 4.1. Instead, decisions are often described as one-time problems. C2 applications are however *dynamic* in the sense that the outcome of one action determines possible actions in the next time step. New information, gained as time passes, should have an effect on which decisions are chosen.

As suggested by Wiener in 1948, the academic field of *Cybernetics* highlights the interaction between dynamic systems [Wiener, 1948]. These systems can represent entities in many areas, spanning from sociology, and biology, to physics, and mechanics. In the latter domains the closely related *Control Theory* [Åström, 1968] [Stefani *et. al.*, 2002] has proven to be very successful. The stated problem in Control Theory is to influence the controlled system to behave

according to a reference value. By accurately analyzing the dynamic properties of the controlled system it is possible to design a *controller* to achieve this goal. In the *open-loop* control system it is required that the controlled system reacts exactly as expected on signals from the controller, see Figure 4.1. Referring to the discussion above on conjecture and refutation, this is equivalent with the problem of induction: Since there can never be exact models, the result of the control signal will always deviate from what was expected.

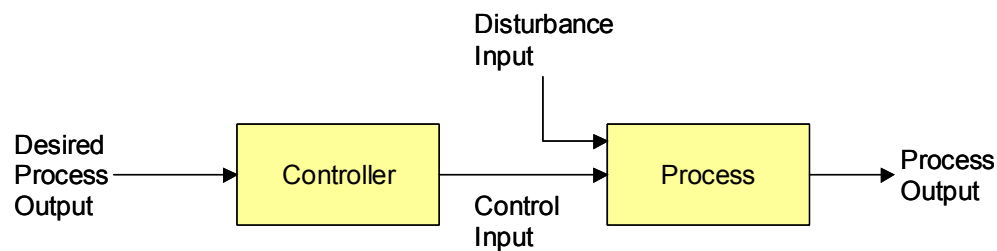


Figure 4.1. The open-loop control system.

To deal with this problem, the concept of *feedback* to compensate for disturbances and poor modeling has been given a prominent position within Control Theory and Cybernetics. Hence, the induction problem is dealt with in a structured manner by the *closed-loop* control system, see Figure 4.2. In such a system, the controller reacts on, not the reference value, but on the difference between the reference value and the measured state of the controlled system. To this end two terms are considered to be essential in the analysis of the controlled system: It has to be *controllable* in that the state of the system can be forced to take on any desired value by applying a control input, and it has to be *observable* in that any initial state can be reconstructed by examining the system output. A third important aspect in the analysis and design of feedback systems is *stability*. An unstable control system, caused by a too large impact from the feedback signal, will start oscillating. Within Control Theory, these terms are more stringently defined, and there are numerous methods applicable in the analysis of them [Åström, 1968] [Stefani *et. al.*, 2002].

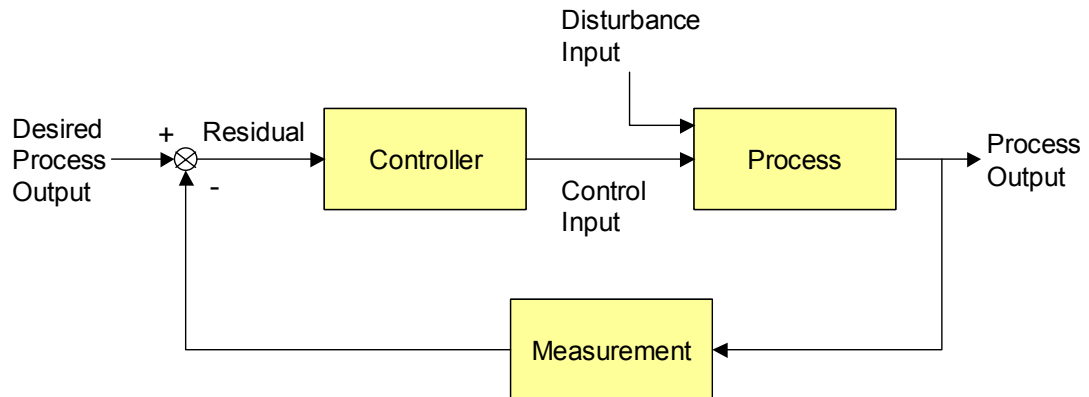


Figure 4.2. The closed-loop control system.

## The OODA Loop and Dynamic Decision-Making

If Wiener were right in that Cybernetics provides tools applicable for different sciences, the ideas of feedback and the closed-loop control system should apply to C2 problems as well. Indeed, there were early attempts to describe industrial management in terms of Cybernetics [Beer, 1959]. Also, some expressions from Cybernetics, such as ‘feedback’, have reached the everyday language of company management. As for the military case, the very term ‘control’ in C2 indicates a Cybernetic heritage. It is also obvious that the battlefield can be regarded as a dynamic system, whose state depends on decisions and actions performed by the involved forces as time passes.

A common model of the dynamic perspective in military decision-making is the *OODA Loop* depicted in Figure 4.3. Coined by Col. John Boyd in the USAF, this acronym stands for Observe – Orient – Decide – Act [Richards, 2001]. According to this model, fighter pilots continuously first use observations from sensors, to orient themselves on the meaning of the situation, and from that make decisions and perform actions. Then, the cycle starts all over again, by observing the results of the performed actions. The faster this loop is compared to the opponent’s loop, Boyd concludes, the more certain the pilot would be to win the battle.

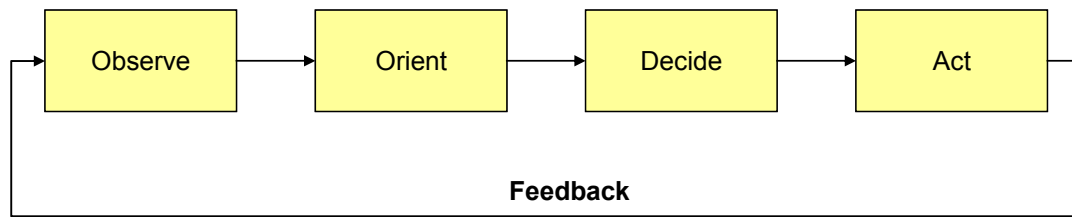


Figure 4.3. Boyd's OODA Loop.

The emphasis on observation and feedback in the OODA loop gives at hand that the own system with sensors, pilots, and the situation involving the participating fighters can be seen as a closed loop control system. There is also a competing closed control loop involving the adversary pilot who also aims at controlling the situation. It can, however, be argued that only the dynamics of the controlling system, i.e., the C2 process, is part of the analysis, while the controlled system, i.e., the battle space consisting of different forces, is lacking in the OODA loop. For instance, the time to get the fighters cleared before they can take off is not part of the OODA loop, although this parameter is of large importance in the analysis of the total performance [Brehmer, 2003]. Consequently, the overall system dynamics is dealt with in a more structured and holistic manner within the research on *Dynamic Decision-Making*. This is a psychological and experimental field that explicitly refers to Control Theory [Brehmer, 1992]. Another approach in this direction is described by [Worm, 2002], suggesting a framework based on Control Theory that represents a Tactical Joint Cognitive System, with its inherent C2 and intelligence processes. By this framework, Worm shows, it is possible to measure the relations between workload, time pressure and stress levels by the individuals within the system, and from this draw conclusions on the overall system performance.

## 4.3 Decision Processes

### Classical Military Planning Models

Most often, the military organizations on different levels have rules on how the planning process should be performed. Among these *planning models*, [Thunholm, 2003] mentions the Strategic Commanders

Guidelines for Operational Planning, (GOP) [NATO, 1998], US Army Field Manual (FM) [US Army, 1997], and the Swedish Army Regulations, Part 2 (AR2) [Swedish Army, 1995]. The purpose of these prescriptive models, according to Thunholm, is to:

- Act as check lists to capture earlier experiences on what should be considered in the planning process.
- Support training of personnel in planning and making decisions.
- Help coordinating the planning work, since people are trained to act according to these models.
- Improve the quality of decisions.

Typically the planning models have an analytical emphasis and are performed strictly sequentially. The goals are set up from an assessment of the mission and the situation. After that, several alternative *courses of actions* (COAs) are developed in close detail. The COAs thus provide descriptions of how the events in the battle space will develop. These descriptions are then assessed according to goals and success criteria to finally make a decision on which COA to execute. With regards to these different criteria for selection, the planning models can be classified as applications of Multiple Objective Optimization.

Military planning models provide detailed descriptions of the decision work in C2, in terms of how individuals relate to entities, and how these entities relate to each other during the planning process. They thus provide powerful input to our design of support tools for C2. We need to be careful, however, since the planning models mentioned are prescriptive and as such they do not necessarily represent the C2 work as it is performed in practice. As discussed before on tacit and informal organizations, there may be a lot of C2 work not performed according to formal rules.

## Naturalistic Decision Models

The suspected difference between prescriptive planning models and decision-making in practice has triggered research within the area of *Naturalistic Decision-Making*.

The *Recognition-Primed Decision Model* [Klein, 1989] describes how experienced military commanders (but also how maintenance officers, design engineers, as well as paramedics) make decisions. As Klein argues, there is no time to develop and evaluate several decision alternatives. He also shows that almost all decisions are made very early in the process, based on the decision-maker recognizing the situation from previous experiences.

The *Recognition Planning Model* (RPM) [Schmitt and Klein, 1999] aims to be both descriptive and prescriptive, as it provides a routine to follow for the commanders that also is well suited to their cognitive capability and the natural way to performing. The RPM starts with an awareness of the situation, and the planners recognizing a need for action. The first step is to identify the mission and at the same time conceptualize the course of action (COA). The second step is to analyze and to operationalize the COA, by investigating whether execution will meet the requirements, and to work out the COA in details. The third step is “Wargaming” to further evaluate the plan and for the executors to learn about contingencies and needs for synchronization. The fourth step is to develop the order, i.e., necessary execution documents. Schmitt and Klein argue that this step may be automated in the future, capturing the plan from the cognitive part of the process.

The *Planning Under Time Pressure* (PUT) model [Thunholm, 2003] is built on the RPM but also on findings from other areas capturing human deficiencies to make rational decisions under high pressure. These mainly include how to deal with uncertainty and complexity. The PUT Model consists of three main events, divided into several sub steps. Each of the three main events aims to answer one of the following questions:

- “What must be achieved?” to identify the task and hence produce a goal state image.

- “How can this be achieved?” to define and chose among possible courses of actions on the conceptual level. Further output from this step includes criteria for success.
- “How should this be achieved?” to develop a detailed plan.

The model thus goes from a rather intuitive process with high involvement of the commander, to a more analytic process in which the staff may work without direct command. It also goes from defining abstract and conceptual solutions to the task to detailed descriptions.





## Chapter 5

# Situation Awareness

One of the central aims with the RMA efforts in different countries is to achieve *Dominant Battlespace Awareness* (DBA) [Blaker, 1996], [Jönsson *et al.*, 1998]. By utilizing modern network and sensor technology together with information processing capabilities, one will get a much better view of the situation than the opponent has. Hence, at least in theory, one will be able to launch much more focused actions and consequently achieve a substantially higher effect from the weapon systems. Better awareness of the situation, in combination with faster decision-making, as discussed in Section 4.2, will give a tremendous advantage compared to the adversary, according to the advocates of Network Centric Warfare [Alberts *et al.*, 1999]. Although it is difficult to prove this general assumption, some research aims at quantifying the assumed positive effects of increased amount of information [Kuylenstierna *et al.*, 2003].

Consequently, the concept of *Situation Awareness* (SA) is of great interest when studying support for C2. Thus, we will give an overview on how this concept can be defined and modeled, and also propose a classification of support tools, including Command Support, Decision Support, and Data Fusion, that can enhance SA in the perspective of C2.

## 5.1 Situation Awareness

### A Definition of SA

One approach to define SA has been suggested by [Endsley, 1995]. In this work, it is clearly stated that SA provides the input to decision-making:

*The operator's situation awareness will be presented as a crucial construct on which decision-making and performance in such systems hinge.*

In the model suggested by Endsley, SA refers to knowledge of a dynamic environment. Hence, more static knowledge, such as on rules and procedures, is excluded from the term. In Figure 5.1, Endsley's model of SA is depicted in the context of a dynamic decision-making loop. According to this model there are three levels of SA:

- *Level 1* represents the perception of the elements in the environment within a volume of time and space.
- *Level 2* represents the comprehension of their meaning.
- *Level 3* represents the projection of their status in the near future.

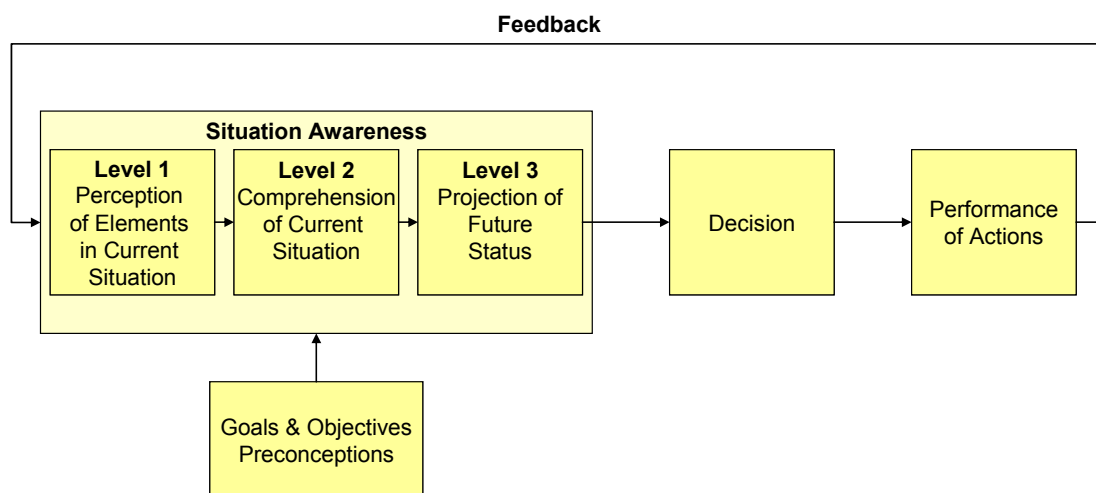


Figure 5.1. Endsley's model of Situation Awareness.

According to Endsley, SA is a state of knowledge, contrasted to *Situation Assessment*, which is the process of achieving this knowledge. Consequently, the act of Situation Assessment, resulting in the three levels of SA, corresponds well to the Orient phase in Boyd's OODA loop in Figure 4.3, providing input to the Decision Making phase.

Endsley's definition of SA has however been criticized for its strictly individual perspective. [Artman, 1999], e.g., maintains that SA should be defined in a perspective of interaction between individuals,

artifacts, rules and culture as a system that makes decisions. Hence, he gives the following definition of SA, focusing on a common and active process:

*Two or more agents' active construction of a situation model which is partly shared and partly distributed and from which they can anticipate important future states in the near future.*

Disagreeing with Endsley, this definition does not make the distinction between SA as a state of knowledge and the process to achieve this knowledge. It shows, however, that there is a part of SA that cannot be derived from the real world in a strictly objective sense. One aspect of this is that it is the observer who controls the attention, which means that information does not just come by itself. Also, the interpretation of the situation is a construction of definitions based on subjective assessment of the relevance of the different entities and relations in the situation, and on a creative process in assembling these into comprehensible aggregates. Also, as more than one agent is involved, according to Artman's perspective, these definitions should be based on agreements between the agents, or at least communicated amongst them.

Still we argue that there remains an objective part of SA, since different agents would reach the similar knowledge when observing the same entities in the real world. Presumably the objective part is more prevalent in SA Level 1, dealing with physical elements in the environment, whereas the higher levels of SA, comprehending their meaning, should be more subjective.

Another problem with Endsley's model is that very little of the battle-space is directly observed by the commanders. Interpreting Endsley's Level 1 literally, it would be other members of the staff, computer screens, and paper maps that constitute the perceived elements in the environment, rather than aircraft and tanks, which would be of more interest for the decision-making. Hence, in the following, we assume that Level 1 includes also physical objects indirectly observed by means of, e.g., radars and reconnaissance units.

## Shared SA

There are two reasons for sharing information between different positions in the organization. As for the objective aspect of SA, sensor and processing resources can be used more efficiently since the data from them can potentially be useful for more than one decision-maker. As for the subjective aspect, it is of essence that the constructed elements of SA can be shared to promote collaboration among the different decision-makers.

Traditionally, systems for maintaining situation models for military organizations have been platform centric. The communication bandwidth between the units (command and control centres, aircraft, tanks, etc.) has been very limited compared to the communication bandwidth within each unit. The information flows between different units have been explicitly defined and thus inflexible. The information exchange in such a platform centric info-structure is naturally message-based, i.e., certain message formats are predefined for different kinds of reports and orders. Different units have historically used their own sensors and data processing capabilities to maintain their own local models of the situation. This as a result of the difficulty they have had sharing information. There has been little or no means to keep these models consistent between the platforms.

By the development of modern network technology, communication bandwidth has increased significantly. At the same time, standardized communication protocols have made it considerably easier to offer services across all units connected to a network. Thus, the view now can be changed from defining information flows between the platforms to instead defining a common situation model available to all units connected to the network. We hence advocate that support for C2 should be built around a shared situation model. This model should support SA on the different levels in the military organization. The traditional platform centric view will then be replaced by a network centric view, in which the situation model is important rather than the geographical location at which the information has emerged.

## Information Awareness

A decision-maker should not only be aware of the situation, but also of the uncertainty in this awareness. Consequently, [Arnborg, et. al., 2000] coins the term *Information Awareness*, IA, to be added to the concept of SA. To this end, it is argued that the following levels of IA apply to the information representing the SA:

- The *Precision* of the information, representing the degree to which the information agrees with the real world, and with the SA of other decision-makers.
- The *Quality* of the information, representing the degree to which the information fulfils its purpose. Hence, the assessment of the quality needs to be related to the decision-makers' goals.
- The *Utility* of the information, representing the benefit of utilizing sensors and other information resources to increase the precision of the information.

These measures do not necessarily need to represent any objective truth. According to the discussion in the previous section, SA is partly subjective, and hence is IA also partly subjective by the assessment of the decision-maker. Hence, the measures of IA can be represented by subjective probability measures, as defined in Section 4.1.

## 5.2 Data Fusion

Achieving SA is a mental activity that primarily is relying on the human mind and the human senses. Yet, humans have always strived at enhancing SA by the integration of data from different external sources, such as other persons and sensor devices, and combining these with stored knowledge from, e.g., books and databases. The art of defining methods supporting this integration is known as *Data Fusion*. One of many definitions of this field is given by [Steinberg and Bowman, 2001]:

*“Data Fusion is the process of combining data or information to estimate or predict entity states.”*

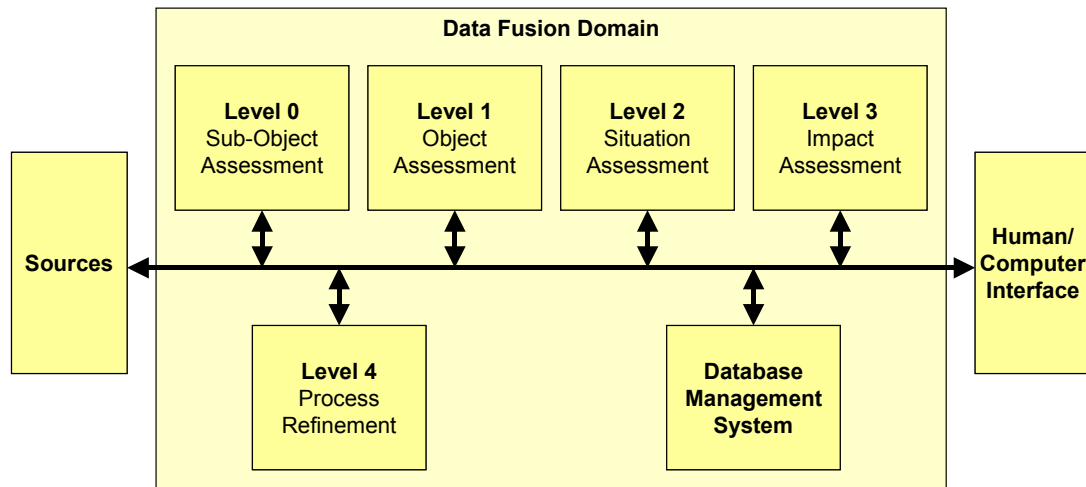


Figure 5.2. The revised JDL model [Steinberg and Bowman, 2001].

Obviously, this definition does not imply anything about the purpose of the concept. The *JDL Data Fusion Model* however gives at hand that Data Fusion is to support SA. The revised JDL Data Fusion model in Figure 5.2, as reviewed by [Steinberg and Bowman, 2001], depicts five interacting levels of Data Fusion, of which Level 1 through 3 clearly correspond to the levels of SA, as defined by Endsley:

- *Level 0, Sub-Object Data Assessment*, is the estimation and prediction on the basis of pixels and signals from different sensors.
- *Level 1, Object Assessment*, is the estimation and prediction of the states of different entities based on observations.
- *Level 2, Situation Assessment*, is the estimation and prediction of the states on the basis of inferred relations among entities.
- *Level 3, Impact Assessment*, is the estimation and prediction of the effects of planned, estimated, or predicted actions.
- *Level 4, Process Refinement*, is the adaptive management of sensor resources and of the Data Fusion processing. This level is related to the concept of *Information Acquisition*, as described by [Johansson, 2003], and to the concept of Information Awareness, described in Section 5.1.

As opposed to SA, which is a mental state, the purpose of Data Fusion, whether performed by manual labor or by the support of computers, is to maintain a model of the situation that is external to the decision-maker. Hence, to support SA in the mental domain, this model, persisting in the technical domain, must be communicated by, e.g., a Human/Computer Interface, such as it is suggested in the JDL model.

According to [Johansson, 2003], the distinction is made between *Multi-Sensor Data Fusion* (corresponding to Level 0 and, in particular, level 1) and *Information Fusion* (corresponding to Level 2 and 3), inferring that the lower levels of Data Fusion mainly rely on reports from different sensors, while the higher levels rely on more refined information. Multi-Sensor Data Fusion to estimate the states of moving targets is also known as *Target Tracking*, which is a well established area with many successful implementations [Blackman and Popoli, 1999] [Wigren, *et. al.*, 1996] [Bergman and Wallenius, 2001].

Although the distinction between data from sensors and elaborated information, as being the sources for the two different categories of Data Fusion, is rather vague, we believe that this separation is practical also from other points of view:

- When estimating object states representing physical phenomena by Multi-Sensor Data Fusion, there is an objective truth that can be grasped for without much interaction with and between operators. Following the discussion in Section 5.1, the higher levels of SA supported by Information Fusion is much more subjective in its character, and there is a part of active construction that needs to be considered.
- The model of the world, by which the different entities can be represented, is rather simple on the physical level. As the relations between entities are estimated on higher levels of SA and Data Fusion, the possible set of states to be estimated becomes much more complex.
- As argued by [Boury-Brisset, 2003], Information Fusion also involves a component of hierarchy, due to vertical organization of military entities, and to multiple levels of abstraction.

- Further argued by [Boury-Brisset, 2003], higher level Data Fusion emphasize on symbolic reasoning rather than numeric reasoning.

### 5.3 Support for Situation Awareness in C2

To conclude the overview of SA and Data Fusion, Figure 5.3 gives an interpretation of these concepts in the context of C2.

In this perspective, there are physical and abstract elements of different affiliations, meaning that if they are of the same affiliation they share goals and are also able to share information. Seen from the perspective of an element of one affiliation, SA on decisions and states of other elements of the same, *friendly*, affiliation should be known by sharing information. The decisions and states of elements of other, *hostile*, affiliations can only be estimated. SA on hostile elements achieved by such assessment should however be shared among friendly elements.

Hence, the complete SA shared among friendly elements includes knowledge of both friendly and hostile elements. This common SA encompasses:

- *SA on Physical Entities*. Perceived physical resources, such as vehicles, soldiers, weapons, and sensors, along with the estimated states of these elements.
- *SA on Friendly Decisions*. According to our definition of C2 in Chapter 2, these encompass 1) decisions on the organization, and 2) decisions on tasks (or intentions), for this organization. The organization, according to Section 3.3, is a multiple and flexible hierarchy with physical resources that have roles in different superior, abstract, resources, such as brigades, task forces, companies, and platoons. In Chapter 7, we will give an extensive model of the entities to be aware of according to this category of SA. The model will include information on potential plans with sub goals and the assessed consequences and utility of these plans. It will also include knowledge on



which of the potential plans that are currently approved, thus representing the actual decision.

- *SA on Hostile Decisions.* This SA encompasses what is known of the organization and intentions of the hostile elements. Hence, it is similar to SA on Friendly Decisions, although there is a larger degree of uncertainty since the actual decisions are not known but inferred.
- *SA on the Game Situation.* The assessment of the hostile decisions ultimately depends on friendly decisions, and vice versa. This game situation, where one party has an assessment of the other party's intentions, which in turn has an assessment of the first party etc., should be regarded in the full development of support for SA in the C2 case. We suggest that knowledge of these dependencies is regarded as a higher level of SA.

As SA is a mental state distributed among decision-makers, there should be means to represent it by use of technical artifacts. Hence, by *Command Support* it is possible to maintain and interact with a *Common Situation Model*, which, in turn, will represent the complete SA, see Figure 5.4.

To enhance the manual work of maintaining the SA by means of the Command Support, different 'clever' tools can be introduced:

- Multi-Sensor Data Fusion can enhance the manual inference of the states of physical resources, friendly as well as hostile. As previously mentioned, this is a mature area, with many implementations, at least for air and sea targets, see, e.g., [Wigren, *et. al.*, 1996]. Physical resources on the ground are more difficult to track, however one approach is being developed by [Sidenbladh and Wirkander, 2003].
- Information Fusion, JDL Level 2 concerning Situation Assessment, can support the inference of hostile organization, see, e.g., [Schubert, 2003].
- Information Fusion, JDL Level 3 concerning Impact Assessment, can support the inference of hostile intentions. [Suzić, 2003] [Lindberg, 2003], and [Runqvist, 2004], all

develop approaches based on knowledge of the enemy's needs and doctrine, combined with observations of the behavior of the hostile units.

- Decision Support can enhance the work on making own decisions on organization as well as on tasks. The development of such support will be discussed further in the following chapters.
- Support based on Game Theoretic approaches can enhance the SA on the Game Situation. Presently, not much work has been performed in this area. [Brynielsson, 2002], [Brynielsson and Arnborg, 2004], and [Gmytrasiewicz and Durfee, 2000], have however suggested some approaches.

In the next chapter we will give one example of how shared SA for entities on the physical level can be supported. In Chapter 8, we will expand further on how the Common Situation Model, the Command Support, and the Decision Support, can be implemented supporting the higher levels of SA. As a baseline for these latter tools, Chapter 7 will describe a conceptual model that serves as the ontology for the Common Situation Model.

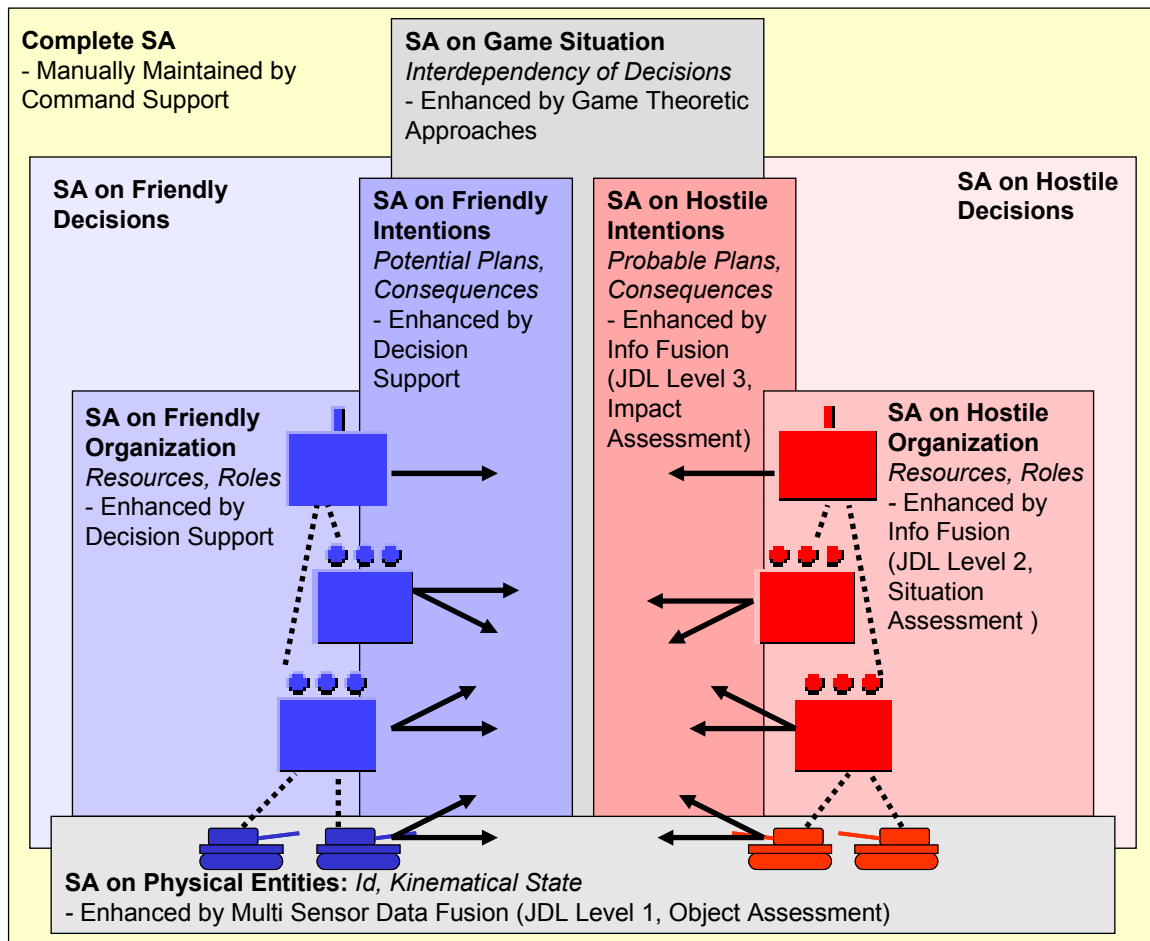


Figure 5.3. Complete SA for the C2 case, enhanced by different support tools.

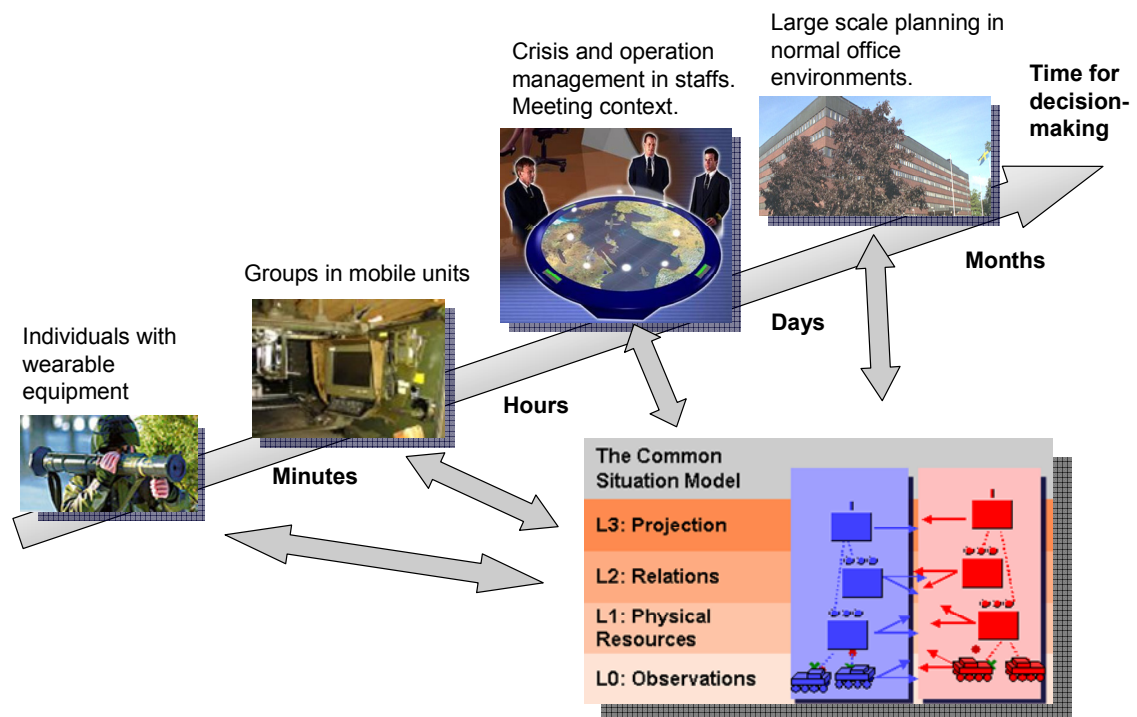


Figure 5.4. A Common Situation Model will support the sharing of all levels of SA among different categories of decision-makers.

## Chapter 6

# The WASP Approach

The major emphasis in this thesis lies on the higher levels of SA. However, to indicate the validity of Figure 5.3, also support for SA on the physical level needs to be described. To this end, we will now outline the concept of *the Wide Area Situation Picture* (WASP<sup>1</sup>), to achieve a common situation picture with the following requirements:

- The approach must give information on moving objects for different users, with common target numbers.
- It must be robust to attacks, jamming and technical disturbances.
- It must fully utilize currently available information resources, such as sensors, C2 centers, data links, and data fusion capabilities (all from many different suppliers).
- It must always indicate the resulting data precision due to the currently available information resources.
- It must be fully scalable, allowing for thousands of users as well as contributors.
- It must be easy to integrate, even with existing systems and data links.

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<sup>1</sup> WASP, MST and MST+, are products of Saab Systems

## 6.1 A Two-Level Approach

To accomplish these requirements on the solution, data fusion is performed on two levels: on the *sensor data level*, and on the *track data level*.

On the sensor data level, active and passive sensors may be of very different kind, measuring from one to three or even more dimensions of kinematical states. A measurement can be a one-dimensional bearing to the target or a complex data record including bearing, range, elevation and Doppler information. A measurement may also give indications that can be used to estimate the object's type or identity. Compared to the JDL model in Figure 5.2, this corresponds to Data Fusion Level 0.

Multi-Sensor Data Fusion is performed to combine these sensor data to estimate which objects there are and their position in the battlespace. The *Multi-Sensor Tracker*, (MST), with their future add-on of automatic type identification (MST+), is one implementation of data fusion in this context [Wigren, *et. al.*, 1996]. The MST is capable of using data from many different sensors, by performing Data Fusion on data from the sensor data level, and providing output on the track level. Compared to the JDL model, this corresponds to Data Fusion Level 1.

Theoretically, data fusion is best performed when data from as many sensors as possible are being used in one tracker by *Centralized* Multi-Sensor Data Fusion. In some cases it is even necessary to feed data from more than one sensor to the tracker, for instance when only passive sensors are used. Thus, it would seem appropriate to have only one data fusion node in the network, using data distributed from all available sensors.

There are, however, several reasons why data fusion on the sensor data level needs to be performed at more than one place and why there has to be means to combine data also on the track level. First of all, the usage of one single MST in an entire system would imply a very vulnerable solution. Redundancy will be needed to meet the requirements for robustness. Secondly, there will always be some sensors that have local sensor data fusion and thus will give data only

on the track level. Thirdly, the connection of centers and systems belonging to other organizations will give tracks in most cases.

By the combination of MST and the WASP, data fusion can be performed on both the sensor data level and the track data level. Together they provide an approach to solve the trade-off problems regarding local or centralized data fusion. The combination of the concepts also meets the requirements for generality regarding connected data sources from different vendors, see Figure 6.1.

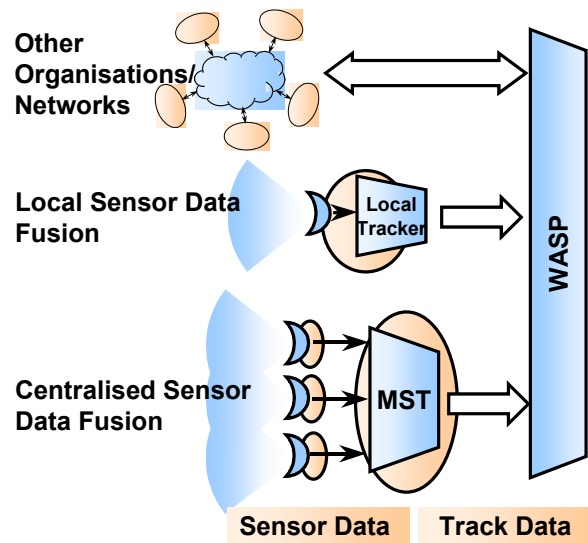


Figure 6.1. Data from both the sensor level and the track level can be utilized by the combination of MST and WASP.

## 6.2 The WCU

The *WASP Correlator Unit* (WCU) is used to perform the correlation of tracks required in the WASP concept. The participating track sources (C2 units, data fusion nodes and networks belonging to other organizations) are thus connected to the network, and to each other, via the WCUs. All software necessary to establish the WASP is encapsulated in these WCUs. Hence, the adaptation effort for each type of track source is kept at a minimum, see Figure 6.2.

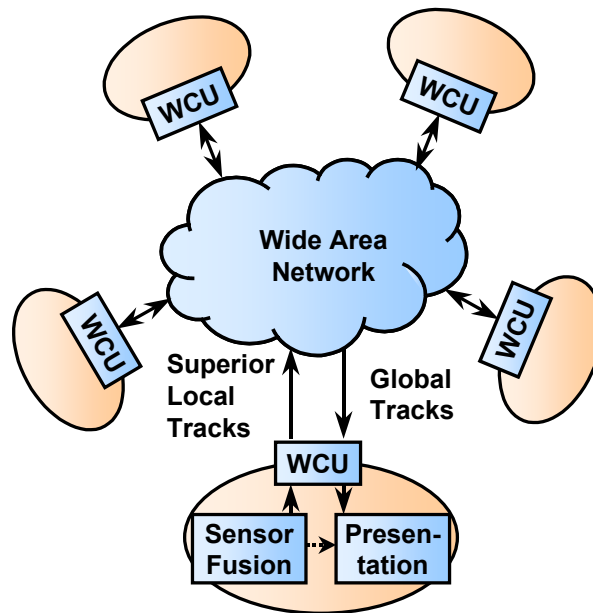


Figure 6.2. The WASP Network: Participating track sources are connected to each other via the WCUs.

The local track data is correlated to the global track data, received from other WCUs (via the network), to determine which tracks that correspond to the same real objects. This correlation process is fully automatic, although it will be possible to perform manual interaction.

Special care is taken in the WCUs to estimate the precision of the tracks. Local data that is either unique or of better precision than the global data, is reported to the other WCUs. In this way the network will distribute only the best track data that is available for each object. Finally, the actual Wide Area Situation Picture is assembled for presentation to the local operators.

To reduce bandwidth consumption, the total surveillance area is divided into smaller subscription areas. For each such area there are several bandwidth levels that can be subscribed to by using multicast services in the network. On the lowest bandwidth level, information on all objects in the subscription area is reported, although at a rather low update rate. Higher accuracy is achieved by subscribing to higher levels, thus requiring more bandwidth in the network.

The WASP concept will be fully scalable, due to the selected correlation algorithm and the use of multicast. Thousands of C2 units



can be connected and there will be no limit on the total surveillance area. Also, the survivability of the WASP will be significant. Although sensors, data links and C2 units may come and go, each operator will still achieve the best quality and consistency from the WASP.

### 6.3 The WASP Prototype System

A WASP prototype system has been developed to demonstrate the concept in an air surveillance application. In this system, a number of computer nodes are connected to each other via an Ethernet LAN. The computer nodes are hosting several C2 units, each consisting of one MST, one WCU, and one display unit. There is also a combined air traffic and radar simulator, and a network simulator, see Figure 6.3.

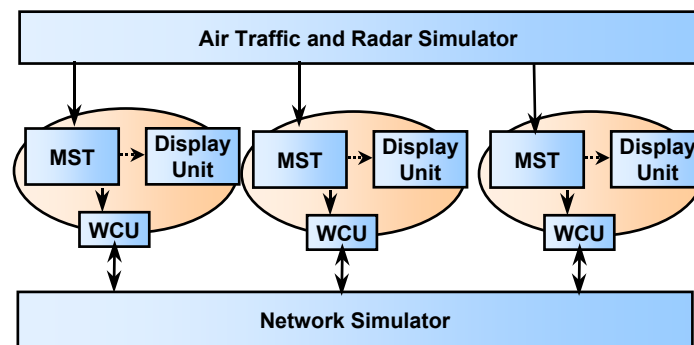


Figure 6.3. The WASP Prototype System.

A large number of radars, observing the same air traffic scenario, can be simulated. Radar plots are thus produced which are used by the MSTs to assemble situation pictures that are local to each C2 unit. The local situation pictures are forwarded to the WCUs, which, in turn, communicate via the simulated network to establish the WASP.

The resulting situation picture presented in each C2 unit is compared to the “truth” in the air traffic simulator to estimate the target accuracy. The estimated accuracy takes into account the performance of available radars, MSTs and data links. In addition to accuracy estimation, the consistency between the C2 units is measured, by comparing the track numbers. Thus, by degrading the simulated network, the performance of the WCUs under severe conditions can be evaluated.

Different sets of data links, sensors, trackers, and C2 units can be evaluated with this prototype system. Used in such manner, the WASP Prototype System serves as an excellent tool for simulation-based acquisition (SBA).

## 6.4 An Example

As an example, the prototype system has been set up using three C2 Units situated in the southern part of Sweden:

- *Unit 1* is a surveillance centre, using two 3 dimensional surveillance radars with typical performance. The rotation time is 10 seconds, and the radars cover a range of 300 km each. Unit 1 is connected to the network with a high bandwidth.
- *Unit 2* is also a surveillance centre, using two radars situated 300 km east of the radars used by Unit 1. These radars are 2 dimensional, meaning that Unit 2 is lacking information on the target altitudes. Unit 2 is also connected to the network with a high bandwidth.
- *Unit 3* is a Surface-To-Air Missile Unit. It uses surveillance radar covering a much shorter range of 75 km. The radar has, on the other hand, a much faster rotation time of 1 second. The network connection for Unit 3 is of very low grade, since the bandwidth is limited to 1200 bits/s.

Figure 6.4 shows screen-shots of the situation pictures displayed in the different units at a moment when the simulated network is entirely jammed out. Since there is no communication, only targets within the range of the unit's own radars can be seen on the screens. The radar coverage is partially overlapping. Some targets can hence be observed by more than one unit. The target numbers are however not consistent between the units, due to the lack of communication. Furthermore, the altitude information can only be seen in Unit 1 (indicated by the second line in some of the target labels).

The color of the targets indicates the estimated quality, in terms of resulting accuracy due to used sensors and limitations of the data links. White targets are of acceptable quality (the resulting accuracy is

better than 500 m) while grey targets are of poor quality (the resulting accuracy is worse than 500 m). Most targets in Figure 6.4 are of acceptable quality, although a few targets of bad quality can be found far away from the sensors.

Figure 6.5 shows the same example, but at a later time when the jamming of the network has ceased. Interaction between the WCUs in the different C2 units is now enabled and the following effects may be noticed:

- Targets that are observed by any C2 unit are displayed also in the other units.
- The targets have the same numbers in all the different C2 units since the WCUs have interacted to agree upon a common target numbering.
- Altitude information is now displayed in all units for targets that are observed by radars belonging to Unit 1.
- Targets in Unit 3 that are not observed by the local radar are displayed at a rather low accuracy (indicated by the grey color). This is due to the limited bandwidth.

A rather good accuracy is required to engage the weapon system from a Surface-To-Air Missile Unit. To avoid using their own radar, the decision-makers in Unit 3 would try to increase the accuracy. The described WASP concept offers several alternatives to consider:

- The decision-makers can try to obtain more bandwidth.
- They can use prioritization to give more bandwidth to important targets
- They can restrict the subscription of external targets to a much smaller area.

If it is decided not to improve the accuracy by any of these alternatives, the SAM unit still has the overview of the situation outside the range of its own radar, and the common track numbers is greatly facilitating co-operation with other units.



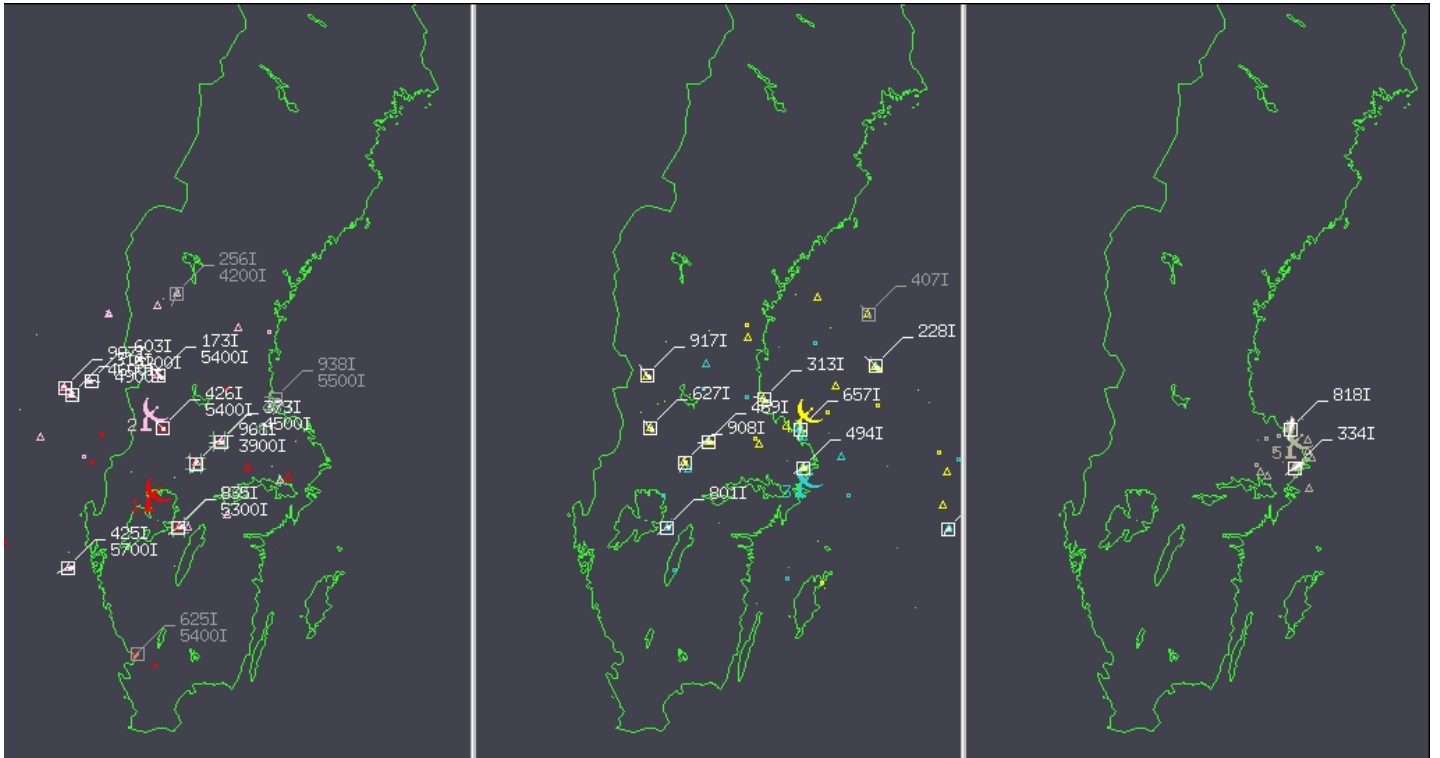


Figure 6.4. Screen-shots taken from the WASP prototype system at a time when there is no communication between the three C2 units.

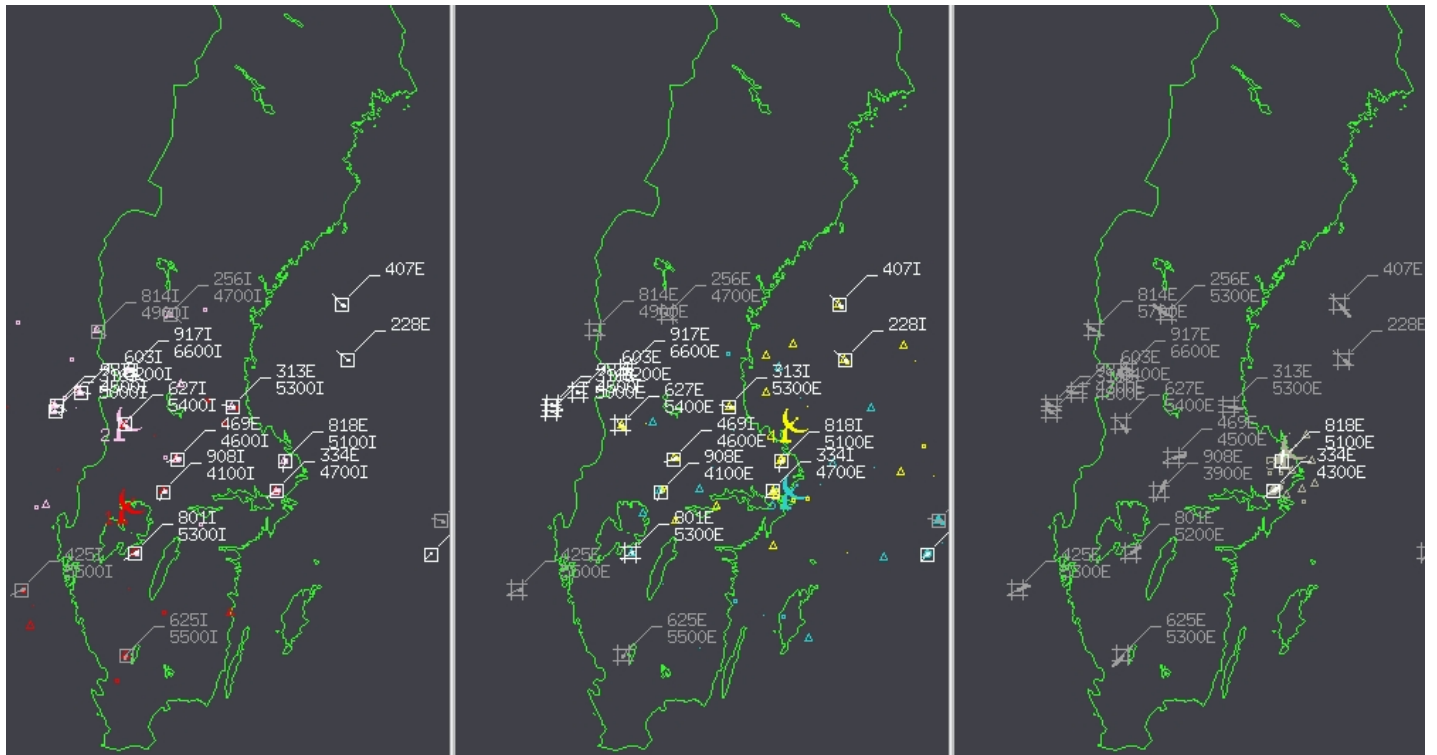


Figure 6.5. Screen-shots taken from the prototype system at a later time when the communication is in operation.



## Chapter 7

# An Ontology for Situation Awareness

In Section 5.3, we argued that a Common Situation Model is required to provide the means to externalize total SA, and to, in turn, facilitate the sharing of it over a computer network and interacting with it through different support tools. Hence, a purposeful structure of the Common Situation Model is vital for the development of the support tools. To this end, the concern of this chapter is to define an *ontology* that expresses essential entities related to the non-physical levels of SA. Also discussed in Section 5.3, SA on these higher levels in the context of C2 regards knowledge of hostile and friendly decisions. Hence, by defining concepts such as resources, roles, organization, plans, tasks, and the decisions regarding these concepts, we will get a more precise meaning of the different matters that were discussed in the previous chapters on C2, organization, and decision-making.

In the AI community, the term ontology has come to mean two things: (1) a representation vocabulary, and (2) a body of knowledge using this vocabulary [Chandrasekaran *et. al.*, 1999]. We refer to the first meaning of ontology by defining a language used to externalize SA by a data model. The role of ontologies has also recently come under focus in the Data Fusion community, e.g., by [Boury-Brisset, 2003] who describes a methodology and a building environment to maintain domain specific ontologies, and by [Matheus, *et. al.*, 2003] who suggests a slightly different approach by describing an ontology for SA that is *generic*, since it can be instantiated for different domains.

Our approach is more related to the latter work, by a model of C2 to represent the ontology, which can be instantiated to express the situation for different positions and levels in the organization. Furthermore, the presented model is drawn from a *conceptual*

perspective, concentrating on the concepts of the domain under analysis. This should, according to [Fowler, 1999], be done with little regard to the software we have in mind. Hence, it allows us to discuss a concept, such as a ‘plan’, without specifying whether it exists in a computer, on a paper, or (tacitly represented) in people’s minds. Thus, the model will be kept independent from technical solutions, further increasing its generality.

The first section of this chapter motivates the use of object-oriented modeling to express the model. After that, the C2 process is depicted by *Use Cases* representing a generic decision-making process. Then the actual *Class Diagram* is presented, defining the different classes of entities and their relations. Finally, to clarify and to conclude the presentation, two examples of situations are given that can be expressed by the use of the model.

## 7.1 Object-Oriented Modeling

The object oriented modeling language *UML (Unified Modeling Language)* will be used to represent the model. The UML is one of several prevailing object-oriented modeling languages, but has grown dominant in the area since it became a standard by the *OMG (Object Management Group)*. Several authors recognize the importance of object-oriented methods in modeling entities corresponding to management, C2, and organization. Curts and Campbell, for instance, argue that, due to its recursive and hierarchical structure, the situation of the battlefield is well suited to object-oriented modeling [Curts and Campbell, 2001]. Cohen, on the other hand, recognizes the increased use of object orientation in the software community as the major driving force in modeling organizations [Cohen, 1998]. Cohen states that objects offer a much more natural way of modeling interaction between agents in an organization than was provided by the constructs in previous generations of computer languages. To these advantages we add that object-oriented methods provide means, including the concepts of patterns and the generalization/inheritance relation, to increase reuse of design efforts. These means offer the possibility to describe problems and to model properties of objects in a generic fashion, considering only common features before instantiation for the specific case.



Although the object oriented model will express concepts more strictly compared to using natural language and ad hoc graphical notation, it can be showed that ambiguities may rise when using the UML. Formal approaches have been made in adapting the language to avoid such ambiguities [Yi, 2002]. Also [Matheus, *et. al.*, 2003] use a formal definition addition, in addition to the use of UML notation, to express the model of SA. While this aspect is not regarded in the present work, it would be of great interest to look into such approaches in the future.

As object oriented modeling languages mainly constitute tools for systems designers and computer programmers, they provide several different techniques and a large amount of special language elements. We argue that only a small subset of these elements is needed to model concepts to the level of our purpose. According to Fowler, the techniques of *use cases* and *class diagrams* are essential when applying the UML for communication between systems designers and domain experts. Use cases help to investigate the interactions between different actors and the system, while the class diagrams help to communicate the deeper conceptual understanding of the world. The features of the UML techniques we use will be explained briefly as they are introduced in the following sections. See [Fowler, 1999], for a further introduction to the UML and how to use it in a design process.

## 7.2 The Generic Decision-Making Process

The first step in our conceptual model is to depict the process executed by the individuals performing C2. We argue that the different prescriptive and descriptive decision-methods, described in Section 4.3, should provide essential input to such modeling since C2, according to our definition, indeed is a decision-making process. Since the aim is to make our model generic it would be an advantage if a single model can represent all these different methods. This should be achievable since the perspective is slightly different from the planning models mentioned. Given that the purpose of our model is to provide the baseline for development of technical support systems, the perspective is technical and belongs to the information domain, rather

than the psychological or sociological domains, as investigated by [Klein, 1989] and [Thunholm, 2003].

Consequently, we may perform several simplifications to reduce the number of different entities in our model:

- From a technical point of view, there is no difference between a brief idea of how to solve a task expressed by the commander and a fully developed plan. Both cases should be possible to represent in terms of synchronized subtasks for available resources. We denote such a collection of subtasks a *plan* irrespective of the current stage in the C2 work. As the C2 work continues, the level of abstraction decreases in terms of increased number of subtasks and increased level of details in the requirements of these tasks.
- Accordingly there is no difference whether the decisions are made early in the process, based on one or a few very abstract ideas, or late based on several plans worked out in detail. Since there is no conceptual difference between plans and ideas, we only need to model the fact that several alternative plans may be evolved concurrently.
- A task has external goals and restrictions, set according to its purpose in the superior plan. The goals and restrictions can also be set in terms of internal interpretation on a lower level of abstraction. Thunholm, for instance, mentions *Goal State* and *Criteria of Success* as important entities different from the external orders. These internal requirements on the task can technically be represented as goals for the task that are complementary to the external formulation of the task.

The suggested generic decision-making process is presented in Figure 7.1. According to the bullets above, decision-making always involves defining the goals of a task as well as developing one or several solutions to this task. The development of solutions includes iteration between, on one hand, suggesting improved solutions, and, on the other hand, assessing these solutions. The assessment is performed by predicting the outcome, and by comparing this assumed outcome to the goals. The actual decisions are made when the task, or one of the solutions, is either approved or disapproved. Before execution, these

steps are iterated until there is a plan that is considered to fulfill the goals, and hence can be approved. At execution, these steps are, again, iterated, assessing the currently approved plan and compare it to its alternatives. This is based on new information that is gained as the time passes, just according to the principles of Dynamic Decision-Making and to the concept of conjecture and refutation.

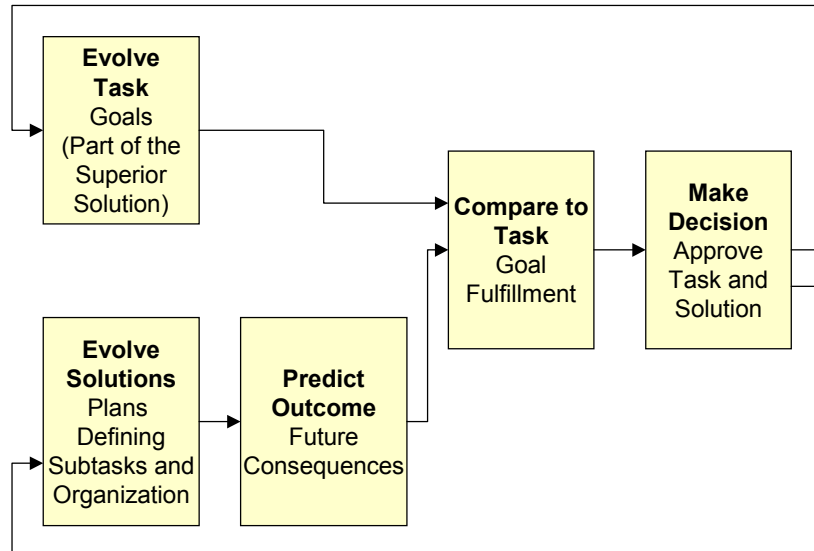


Figure 7.1. The generic decision-making process.

To further illustrate the Generic Decision-Making Process, we apply the technique of *Use Case Diagrams*, see Figure 7.2. Use Case Diagrams show *actors* and their interactions with the system, represented by *use cases*. Since our model is drawn from the conceptual perspective, ‘system’ must refer to a fictive system of artifacts, mental models and computerized concepts. An actor can be an individual, a group of individuals, or another system.

The actors identified from the different planning models include the commander and the staff belonging to the unit, but also the superior commander for some higher-level unit and his staff. These actors should not be taken literally, however, as they merely are provided to exemplify who may perform certain interactions. It is more the span of possible use cases that is of interest. Nevertheless it is assumed that these actors perform the decision-making as a collaborative process.

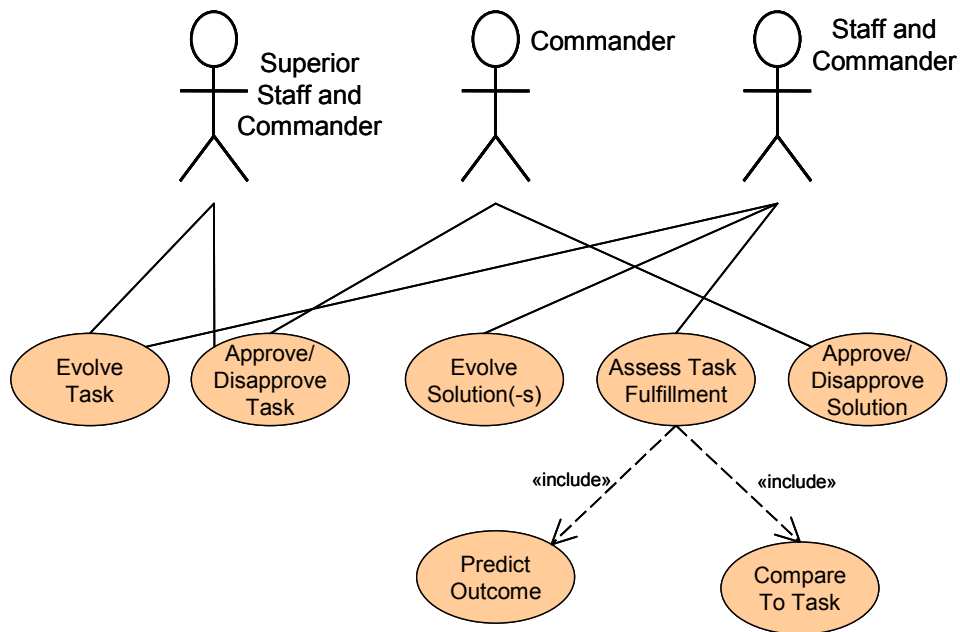


Figure 7.2. Use cases depicting the generic decision-making process.

The following events describe a typical example of how the use cases can be applied:

- The superior decision level has assigned a task to the unit (applied use cases: Evolve Task and Approve/Disapprove Task).
- The external goals are assessed and internal goals are set up, including a goal state vision (Evolve Task, Approve/Disapprove Task).
- One or several solutions are invented and developed to a suitable level of detail. This includes at least some assessment of feasibility according to the task (Evolve Solutions, Assess Task Fulfillment).
- The outcome, given the different solutions, is predicted by mental or computer-based simulation, war-gaming, etc. (Predict Outcome).
- The assessed outcome is compared to the goals (Compare to Task).

- The commander makes a decision, by approving one of the solutions (Approve/Disapprove Solution).
- If neither of the solutions is feasible, further evolution is necessary or the goals may have to be changed (Evolve Solutions, Evolve Task).
- If needed, further detailing of the approved solution is performed (Evolve Solutions).
- When the execution of the mission starts, the staff will continuously assess task fulfillment by predicting the outcome of the current approved plan (Assess Task Fulfillment). If needed the process starts over again.
- After the execution, it is assessed whether the task has been fulfilled or further actions are necessary (Assess Task Fulfillment).

We argue that the decision-making process depicted by Figure 7.1 and Figure 7.2, captures all of the models mentioned in Section 4.3, under the condition that the actors and the different steps above are not taken too literally. Further evidence for this claim should be possible to gain by examining the different models in detail to see if they apply to the use cases indicated in Figure 7.2. This is, however, beyond the scope of this thesis.

## 7.3 The Class Diagram

### Resources

From the use cases in Figure 7.2, we recognize that the concepts of tasks and solutions should be essential to the model. From a slightly different point of view, we however start with modeling the resources that may be assigned to perform these tasks as part of a solution on a superior level. The resources can depict physical entities such as tanks, ships, and human personnel but they can also represent small and large organizations spanning from, e.g., mechanized platoons and companies to the entire United Nations. According to the discussion

in Section 3.3, we also acknowledge that resources may be dynamically subordinated to multiple organizations. The design of a proper organization constitutes a prominent part of the C2 work to solve a task at hand, according to our definition and to the previous discussions.

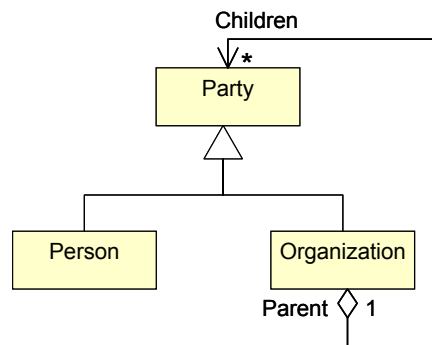


Figure 7.3. An example of class diagrams, depicting the Party Composition Structure [Fowler, 1999].

In the class diagrams *classes* of objects are identified. Two main kinds of relationships between classes can be modeled: *associations* and *subtypes*. We apply the *Party Composition Structure* [Fowler, 1999] to give an example of both of these relationships, see Figure 7.3. Indicated by the triangle, the classes *Person* and *Organization* are both subtypes of the class *Party*, i.e., the *Party* class is a more general concept than *Person* and *Organization*. This relationship is motivated by that a person and an organization show similarities that can be captured by a common super type. One such similarity is depicted in the diagram, in that both organizations and persons can be children of an organization. The arrow captures this feature, by showing possible associations between *Party* and *Organization*. Also indicated in the diagram is that a party always has one parent (by the ‘1’), and that an organization can have any number of children (by the ‘\*’).

An object diagram provides an example of how objects can be configured governed by the definitions and restrictions given in the class diagram. Figure 7.4 depicts one such instance consistent with the class diagram from Figure 7.3. In this object diagram, different battle units, together with a staff unit, are all instances of *Organization*. There are also some individuals that are instances of *Person*.

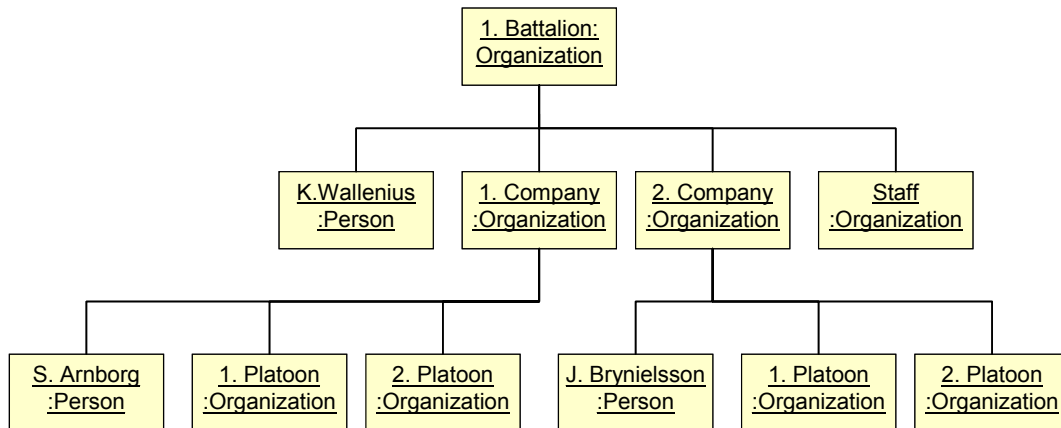


Figure 7.4. An object diagram exemplifying an organization of subordinated persons and organizations in accordance with the class diagram in Figure 7.3.

The recursive party composition structure is of large interest to us, since it can model an organization of any depth, and since it treats persons and organizations in similar manners. Changing the name from ‘Party’ to *Resource* would, however, results in a larger emphasis on these similarities from the C2 point of view.

Real persons as well as whole organizations serve as resources when solving tasks on a certain level of abstraction. We see that, apart from persons, there are also other types of *Physical Resources*, such as tanks, computers, and ammunition, which hence are subtypes of *Resource*. In contrast to the physical resources that may be observed by sensors in the physical reality, *Abstract Resources* are the result of subjective decisions according to the discussion in Section 5.1. An *Organization* is an example of an abstract resource, of which a *Unit* represents a long-term organization where the commander has full command of the subordinated resources, while the *Virtual Organization* represents other forms of organizations to which the subordinated resources are more weakly connected. In addition, we suggest that *Spatial Objects*, such as areas, points, routes, etc., also should be subclasses of *Abstract Resources*. Hence, a few examples of *Physical* and *Abstract Resources* are given in Figure 7.5.

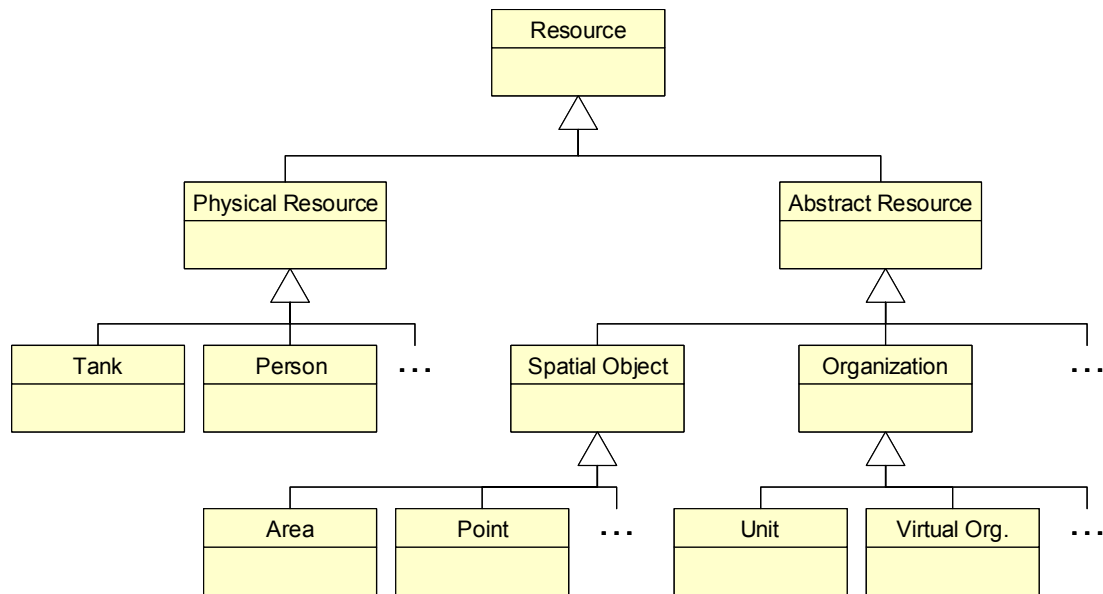


Figure 7.5. Examples of physical and abstract resources.

## Roles

One of the main issues is that there must be means to model multiple and dynamic organizations. By the *Accountability Pattern* [Fowler, 1997], e.g., a local sales office in a worldwide company can have *Accountability* both to the local subsidiary and to the global sales organization. We follow this design pattern, although the name of the connecting class is changed to better align with C2 vocabulary. Hence, we let the *Role* class represent a directed connection defining the subordination of one resource to another. A Role can depict any such directed relationship between two resources. As such, it can also be seen as a membership to a superior resource or the means to represent aggregation. By letting each resource having any number of roles, one can consequently model multiple organizations. In the class diagram, depicted in Figure 7.6, we see that resources can have any number of superior as well as subordinated resources through different instances of the Role class.



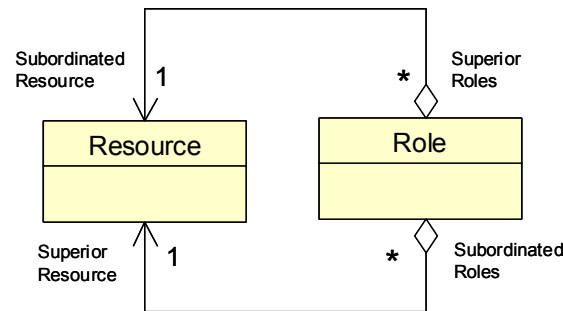


Figure 7.6. Roles permit memberships to multiple organizations.

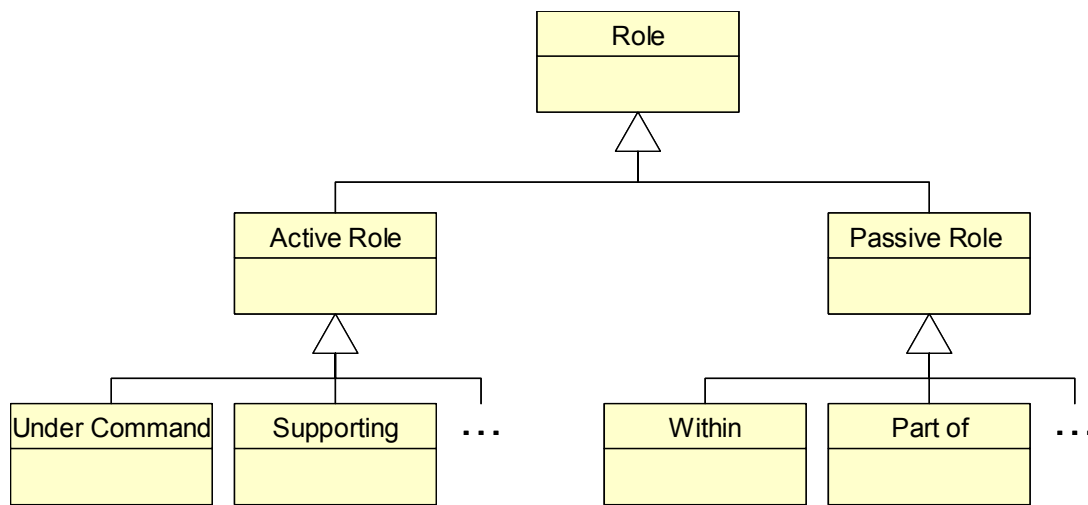


Figure 7.7. Examples of Active and Passive Roles.

In Figure 7.7, some examples of *active* and *passive* roles are given. A resource having an active role in a superior organization means that the resource may be assigned to tasks within this organization. A passive role, on the other hand, depicts directed relations by which such assignments would not be applicable. An example of the latter is the *Within* role, modeling that, e.g., a unit is located within a certain area.

With different roles there may come different kinds of privileges and obligations in accordance with prevailing explicit or tacit doctrines. The meaning of ‘subordination’ and ‘commanding’ may be very dissimilar for different organizations. Although these issues are not currently part of the suggested model we believe that introducing different types of roles might capture some of these matters. Hence, a resource supporting another resource and a resource being under

command of another resource can both be represented by roles, as suggested in Figure 7.7.

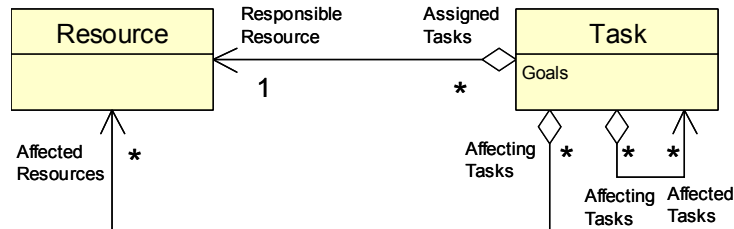


Figure 7.8. A Task can be assigned to a Resource, and can affect other Resources as well as other Tasks.

## Tasks and Assignments

Assigning a *Task* to a *Resource*, according to Figure 7.8, represents a decision that the *Resource* is expected to achieve some *Goals* (although it actually is the *Roles* in superior *Resources* that will be assigned to the *Tasks*, as we will see later). The goals, according to the discussion in 7.2, encompass different kinds of external and internal expectations. Negative goals, i.e., *Restrictions*, are thus also represented by this attribute. Tasks assigned to *Resources* of hostile affiliations may be used to represent what is known of the enemy's activities and intentions.

A *Task* may have associations to other *Resources* or *Tasks* that are affected by its goals. Hence, a *Task* to defend something may be associated to some *Resource* or other *Task* that is the subject, or the scope, of the defense, such as a certain area, a radio station, or some activity.

Some examples of tasks are suggested in Figure 7.9. These are divided into three categories, *Perception Tasks*, having to do with gathering of data on states in the real world, *Cognitive Tasks*, dealing with processing these data and making decisions, and *Effectuating Tasks*, having to do with changing states of the real world.

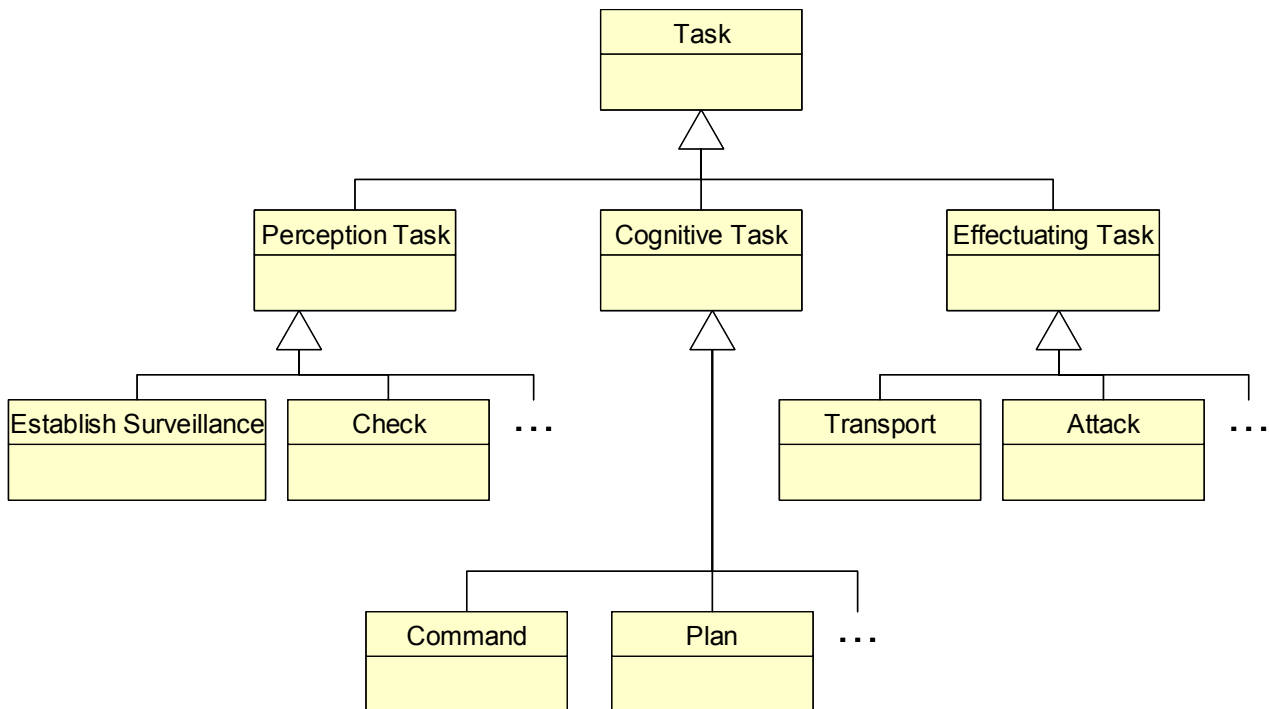


Figure 7.9. Examples of different Tasks.

## Task Types, Capabilities and Services

To model virtual organizations, it is of interest to represent that different subordinated roles give different rights for the superior resources to assign tasks to the subordinated resources. Although defining different kinds of roles, such as in Figure 7.7, may solve parts of it, Figure 7.10 depicts further elaboration on this issue. By introducing a *Task Type* class, it is possible to model the *Capabilities* of a resource, representing which types of tasks that a resource can take on. Further on, it is also possible to model the *Services* offered through a role, representing which of the capabilities that the superior resource is allowed to utilize.

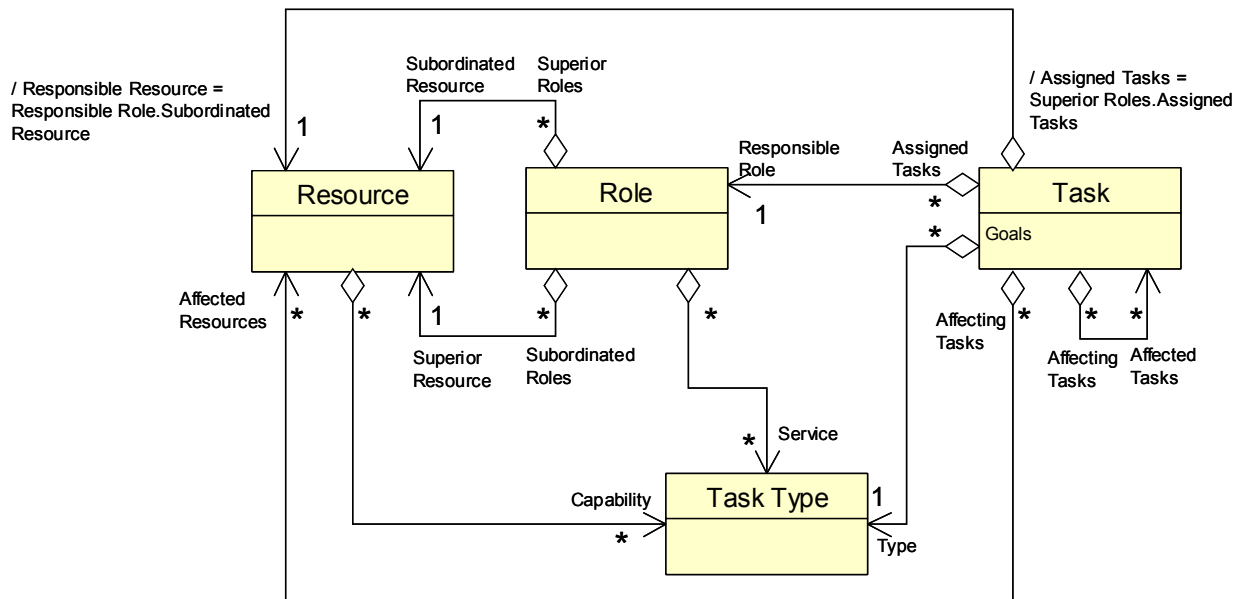


Figure 7.10. Modeling Capabilities and Services by a Task Type class.

To make this work it is necessary to keep track of which role the task is assigned, rather than to which resource, as was the case in Figure 7.8. By this conduct, it is also possible to deduce from which superior resource the task is generated. Still, the direct association between a responsible resource and an assigned task can be derived, indicated by the *derived association* expressed by the ‘/’ in Figure 7.10.

## Plans

A *Plan* represents the solution to a superior task. Several alternative solutions can, consequently, be represented by multiple plans. A plan must then represent possible decisions on the organization, constituted by subordinations of resources by their roles. It must also represent tasks that can be assigned to these roles. Making a decision on organization, tasks, and assignments, is then equivalent to *approving* a plan by selecting one of the potential plans for further execution. Accordingly, it is the approved plans that together define the current organization and the corresponding tasks.

Putting together all the previous pieces, The Class Diagram in Figure 7.11 captures these further aspects. According to the diagram,

instances of the Plan class define subtasks, resources and their roles and assignments, to represent potential solutions to their superior task. Recursively, the subtasks define potential solutions in terms of plans on a lower level of abstraction. To represent the meaning of ‘define’ in the model, we have applied the *composition* type of associations, symbolized by the black rhombi, to emphasize that there must be one and only one ancestor. Consequently, it is by a plan that a role or a task comes to existence.

To facilitate the generic decision-making process defined in Figure 7.2, the attributes *goals* have been associated with the Task class, and the attribute *assessed task fulfillment* has been associated to the Plan task. To represent the decision, one (at the most) of the potential solutions can be selected, thus gaining the status of being the *Approved Solution*.

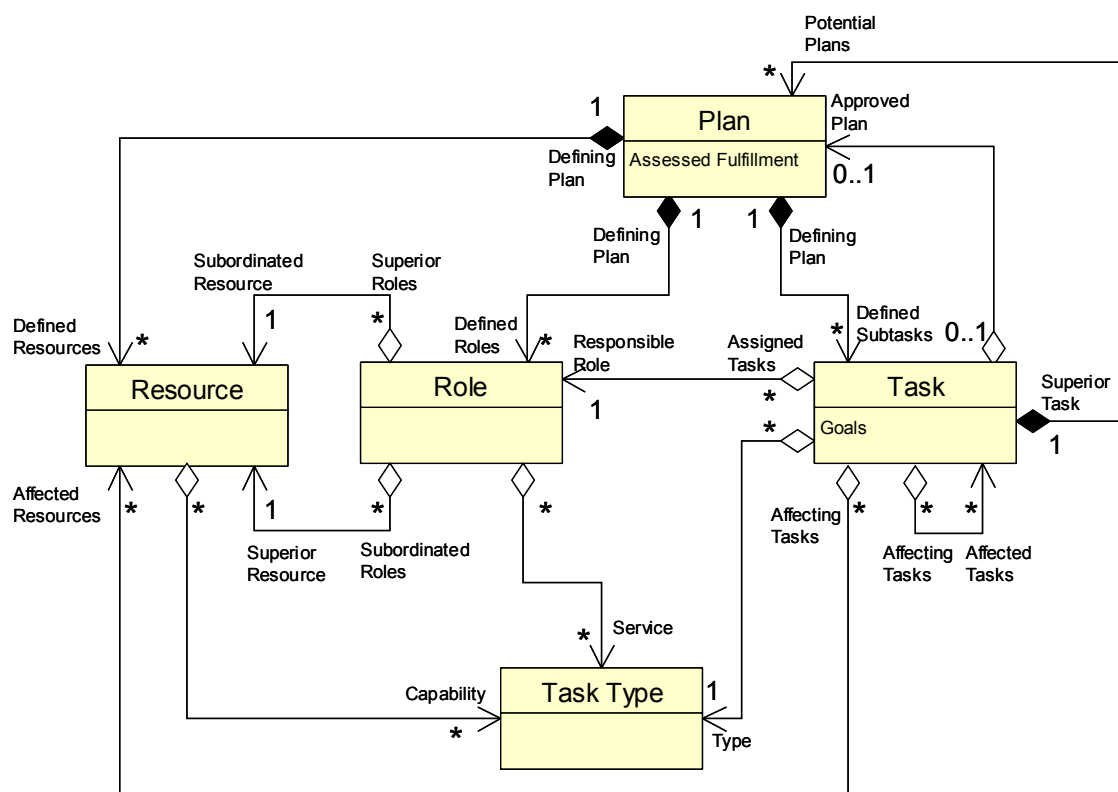


Figure 7.11. The complete model with plans representing solutions for superior tasks by defining resources, roles, and subtasks.

## 7.4 Two Examples

The class diagram in Figure 7.11 concludes the model of C2. By this model it is possible to express the entities that are required by the use cases in Figure 7.2, defining the decision-making process in C2. The Plan class is used to represent solutions of subtasks, solving the superior task. Making decisions is expressed by approving one of alternative plans defining different sets of resources, roles, and tasks. Evolving and approving the task is hence equivalent with evolving and approving its superior plan.

The model of C2 provides an ontology, by which SA can be represented. We will now finish the presentation of this model, by giving two small examples of how a situation can be expressed.

The first example, presented in Figure 7.13, illustrates a resource that has two different roles. As defined by the Order of Battle, the 101. Mechanized Battalion is under operational command by the 10. Mechanized Brigade. The Battalion has the capabilities to Transport, and to Attack. Both these capabilities are available to the Brigade Commander through the Transport and Attack services. The Brigade Battle Plan further states that there is a local police organization. Expressed by the Transport service, the Battalion is to support this police with transports. Finally, the list of current dispatches, maintained by the police office, defines a certain set of material that is to be transported, by the assignment of a transport task to the Battalion.

The second example, illustrating opponent forces represented on different levels of abstraction, is shown in Figure 7.12. The friendly company, in this example, is assigned the task to attack a hostile company, which, in turn, is believed to defend a radio station. Breaking down this situation to a lower level of abstraction, one of the subtasks to solve the attack task is to scout the radio station. This task is assigned to a platoon that is subordinated to the friendly company. In solving the defend task, the hostile platoon, subordinated to the hostile company, answers by trying to interrupt this reconnaissance.

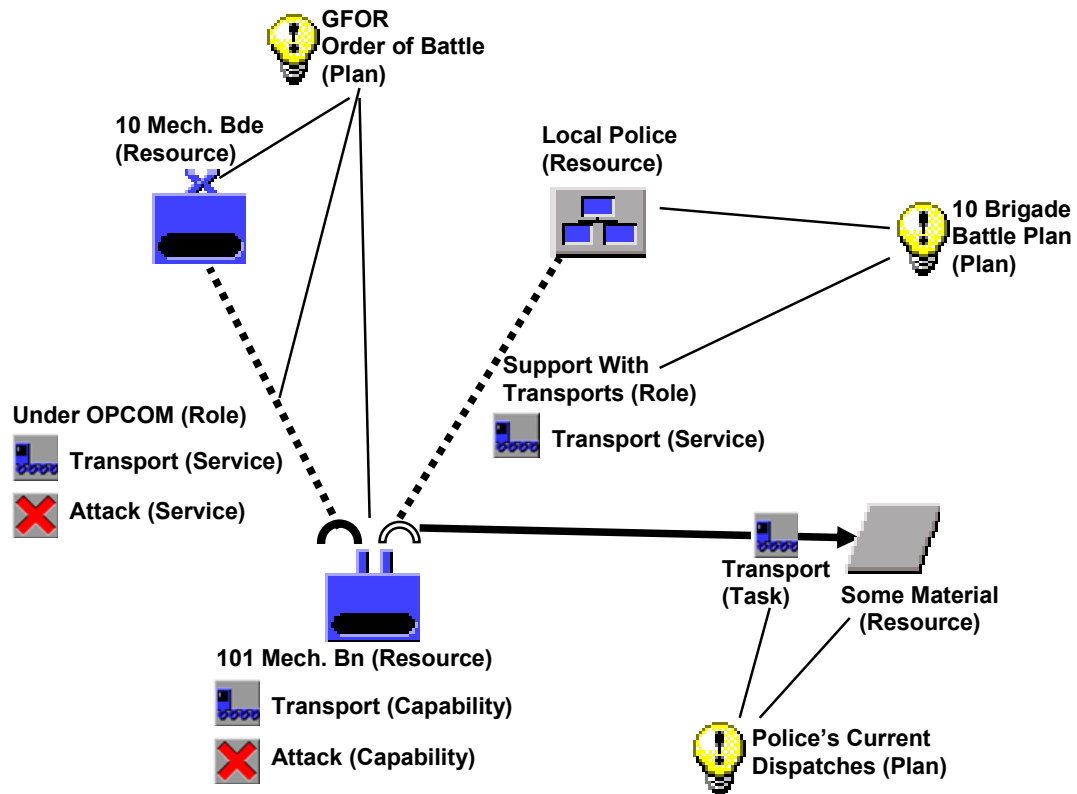


Figure 7.13. An example of a Battalion with one role within the Brigade and another within the local police.

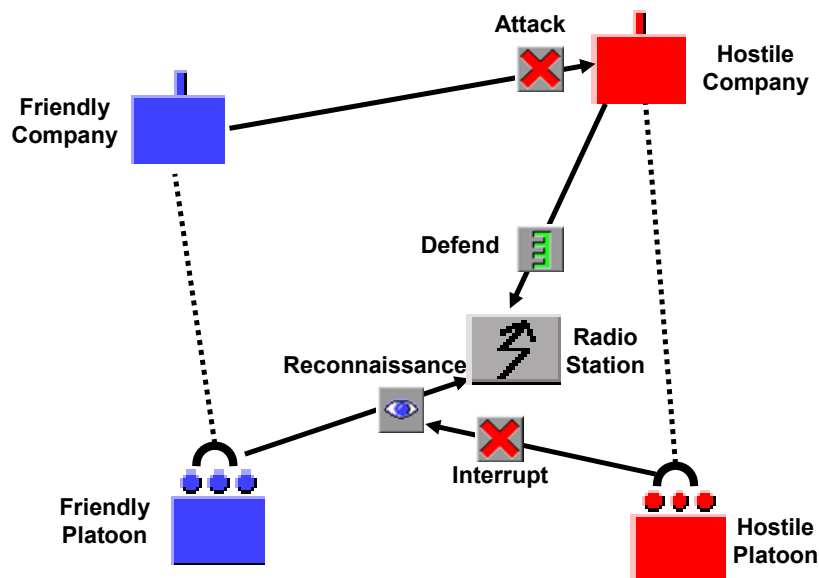


Figure 7.12. An example of a situation with two opponent forces expressed on two levels of abstraction.





## 7.5 Further Work on the Model

The emphasis in the proposed model is on the hierarchical aspects of plans, tasks and organization. In turn these are able to represent own activities and the beliefs regarding hostile intentions. Different Command Support tools can, as we will discuss in Chapter 8, utilize these vertical relations, by allowing the users to browse up and down through the different layers of abstraction.

The approach proposed by [Matheus, *et. al.*, 2003] emphasizes more on the lateral relations between objects in the situation, by defining a very general relation class. Some of the examples given in this work, including ‘Attacking’, ‘Firing At’, and ‘Advancing Towards’, can be expressed by the Task class, according to our model. Other examples, such as ‘In Region’ and ‘Contained Within’, can be expressed by our Role class. Matheus *et. al.* however give further examples of relations, including ‘In Range’, ‘Facing’ and ‘Vulnerable To’, that are not easily expressed by our model. In the work by [Edlund, 2004], such relations are applied to describe situations when recognizing events. The differences between these two models need to be considered in the future development of our work.

Further work also includes more emphasis on the *Type Domain*. The Task Type class admits that the kind of tasks typically assigned to a resource can be modeled dynamically, as part of the daily C2 work. In a similar manner, typical resources and roles can be modeled to represent the regular organization of, e.g., a Mechanized Battalion. Also, it should be possible to model typical plans that, when solving a task of a certain type, constitute the main typical decision-alternatives. This would be of great help when preparing for different tasks in advance. Also, the time aspect, which is emphasized in the work by [Matheus, *et. al.*, 2003], and dependencies between different tasks, need further emphasis.

Another important aspect when modeling the hostile elements is the concept of uncertainty. [Suzić, 2003a] argues that uncertainty is difficult to represent using the UML, and suggests the combination with Bayesian Networks. [Brynielsson and Arnborg, 2004] work

further in the uncertainty area by defining Bayesian games to solve the dependencies between friendly and hostile decisions.

Nevertheless, by representing the ontology of a Common Situation Model, the suggested model will admit the flexible integration of different support tools. Hence, future development of Command Support, Decision Support, Multi-Sensor Data Fusion, and Information Fusion, may be exploited to facilitate awareness of the total situation, including the states and intentions of friendly as well as hostile forces.

## Chapter 8

# The DISCO Approach

The use of computer-based simulation to support commanders in the decision-making process has been considered for a long time. Efforts such as the *High Level Architecture* (HLA) have been the means to perform large scale, and highly complex, simulations to illustrate and learn from processes that strive to resemble the real world [Gagnon and Stevens, 1999]. Other efforts aim to reduce complexity in the simulation models in favor of capturing intangible entities such as for instance cohesion and morale, and to better understand the non-linearity of the consequences of the decisions [Horne, 1999]. The concept of *agent-based modeling* has been suggested to support this latter approach [Ilachinski, 1997] [Ilachinski, 1998] [Woodcock *et. al.*, 1993]. Although they are quite different in their approaches, these efforts tend to result in tools that are separate from other computer-based support provided to the commanders.

Our aim is to support commanders in their work by describing and explaining their intents and decisions, both in terms of brief concepts of how to perform an operation, and in terms of fully developed and very detailed operation plans. By full integration of simulation tools to this support, it would be possible to predict the development of the situation and hence facilitate the higher levels of situation awareness. Also, by offering the opportunity to simulate plans and concepts, as they are designed by use of planning tools in the system, the consequences of potential decisions can immediately be tested during any phase of the planning process [Brynielsson and Wallenius, 2003] [Huang *et. al.*, 2003].

In Section 5.3, it was suggested that, to support full SA, different support tools should be developed to interact with the Common Situation Model. In this chapter we will develop on how these services should be implemented. Hence, in Section 8.1 we will discuss

different aspects of the implementation of the Common Situation Model. In Section 8.2, we will develop on Command Support that enables the manual work to maintain the model. Finally, in Section 8.3 we will describe different issues on Decision Support, enhancing the manual work by replacing some of the human cognitive capacity mainly by incorporating different methods of simulation. Hence, Command Support is addressing mere bookkeeping of the human assessments, while Decision Support is considered being intelligent in some sense. Also suggested in Section 5.3, was the integration with Information Fusion and Multi-Sensor Fusion. Further elaboration on this integration is however left for future work.

To illustrate and test these ideas, a prototype of a system named *DISCCO* (Decision Support for Command and Control) has been developed. Fully implemented, this system will provide services to operators connected to a network, hence supporting their collaborative work in performing C2. The screen-shots in this chapter are taken from the current version of this prototype, *DISCCO 1.0*.<sup>2</sup>

The example scenario depicts a conflict in the fictive country of Gammia to which the UNSC mandated a peace enforcement mission. The example will be further described in Section 9.2.

One particular item mentioned among the decision support tools suggested in Section 8.3, is the generic *GECCO*<sup>3</sup> platform used for implementing different kinds of games for supporting experiments and training in decision-making.

## 8.1 The Common Situation Model

Building on the ontology depicted in Figure 7.11, the Common Situation Model in *DISCCO* is used to share information to support the higher levels of SA, according to Figure 5.3.

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<sup>2</sup> The *DISCCO* prototype and the example scenario have been developed at Saab Systems.

<sup>3</sup>The *GECCO* platform has been developed as open-source software at the Royal Institute of Technology, and the Swedish Defence College.

In the current prototype implementation, the model is represented in a commercial relational database. The requirements regarding availability of the WASP solution discussed in Chapter 6 should however apply also on this shared set of information. Thus, we believe that other, more robust, solutions should be considered.

Also, the interface provided to the other services should be worked out more carefully. To this end, a more detailed data model is to be developed on the basis of the conceptual ontology given in Figure 7.11. In the detailed model, also the different future matters discussed in Section 7.5, regarding lateral relations, the time aspect, further work on the type domain, and the emphasis on uncertainty, should be considered. Also, the relation to the lower level SA, including types and kinematical states of physical entities, should be included.

Ultimately, the scope of the Common Situation Model includes all that is believed of own and hostile decisions, together with references to objects to which these decisions relate. Since this scope is rather large, the complexity of the model is reduced by the exclusion of other types of information, such as information on the environment, e.g., terrain, and infrastructure. Instead, such specific information is referred to, by including links to objects in other databases.

The discussion on tacit organization in Section 3.2 indicates that there would be further numerous aspects of the decisions that cannot be captured by the formal data model. Hence, there also should be the possibility to provide, e.g., multi-media and unstructured text objects, to fill in with subtler and more intangible matters than can be expressed by the model. Again, such information should be linked to, rather than be incorporated, in order to keep the model separated from specific matters.

## **8.2 Command Support**

Command Support aims at helping the commanders in the human, collaborative, and continuous process of developing, evaluating, and executing solutions to their tasks. Hence, these tools provide the means to interact with all entities that are represented in the Common Situation Model. This interaction includes the maintenance of tasks, plans and assessments, and also the dynamic design of the

organization. To this end, the different Command Support tools will be developed in DISCCO to support navigating and editing the Common Situation Model from different *views* including:

- *Hierarchical tree views* that reflect the recursive structure of the model. Figure 8.1 gives an example of a tool to browse the directed graph that represents the Organization hierarchy. In this view it is possible to select a certain resource to browse among its superior, and subordinated roles, and to depict its assigned tasks and the defining plans that, given that they are approved, represent the decisions on all these entities. In turn, Figure 8.2, Figure 8.3, and Figure 8.4, illustrate a tool to browse the corresponding graph representing the Task/Plan hierarchy. From a selected task or plan it is possible to browse up and down its superior and subordinated tasks and plans. Figure 8.2 hence describes a conflict involving civilian and military resources in Gammia, and the task for GFOR to solve this conflict. In turn, Figure 8.3 depicts the GFOR Order of Battle, defining the organization of GFOR, and the tasks for the different higher-level organization units. In Figure 8.4, these tasks have been broken down to the mission for the Swedish 101. Mech. Battalion to establish surveillance of its area of responsibility (denoted 'AOR 101'). In this task view, the goals in different dimensions for the task have been defined, and the two main decision alternatives have been identified. The first alternative is stationary surveillance with fixed observation posts, while the second alternative is mobile surveillance, patrolling the roads in the area. Also, the assessment of potential plans is depicted in this view. This will however be further discussed in Section 8.3.
- *Geographical views* that illustrate the entities in a geographical context, i.e., on a map. While traditional situation pictures, such as in Figure 6.5, emphasize the positions of different resources, it will, by means provided by the Common Situation Model, be possible to depict also tasks and other relationships. In addition it will be possible to select the appropriate level of abstraction, by zooming up and down through the recursive structures. Two examples of geographical views are given. Figure 8.5 shows the situation in Gammia on a rather high level, while

Figure 8.6 has zoomed in to the situation in a smaller area. Tasks are not shown in the Geographical views in the current implementation of DISCCO. When this is implemented, the Geographical views will be considerably more informative, by giving information, e.g., according to the situation in Figure 7.12.

- *Time views* that depict the extension of the entities in time. Typically, tasks will have definite or assessed points in time when they are expected to start and end. There will also be dependencies between entities, e.g., a certain task must not start until another task has been finished. These temporal aspects are however not yet part of the model, as previously discussed. Consequently, there are no examples of time views in the current version of DISCCO.

Similar operations on entities, such as defining that a resource is subordinated another, may be performed in different views. In the Task/Plan tree view, this would be achieved by a ‘right-mouse-click’ to define a new role in the ‘Defined Roles’ field. In the Organization tree view, the same operation can be performed by a simple drag-and-drop action. Defining tasks and assigning them to roles will be performed in the Task/Plan view, but it can just as well be performed by actions in the Geographical view.

The plans are the fundamental entities, defining all other entities in the model. Hence, approving a plan is equivalent with making the decision that these entities, and the relations between them, shall come to existence. Since the plan, with its defined entities, is available to subordinated resources, a decision to execute a plan is equivalent with issuing orders to the subordinates. Given this importance, the management of the plans should be given particular emphasis. Thus, handling of different versions of plans should be included among the Command Support tools. Perhaps also further stages representing the status of a plan, than the current ‘not approved’ and ‘approved’, would be needed.





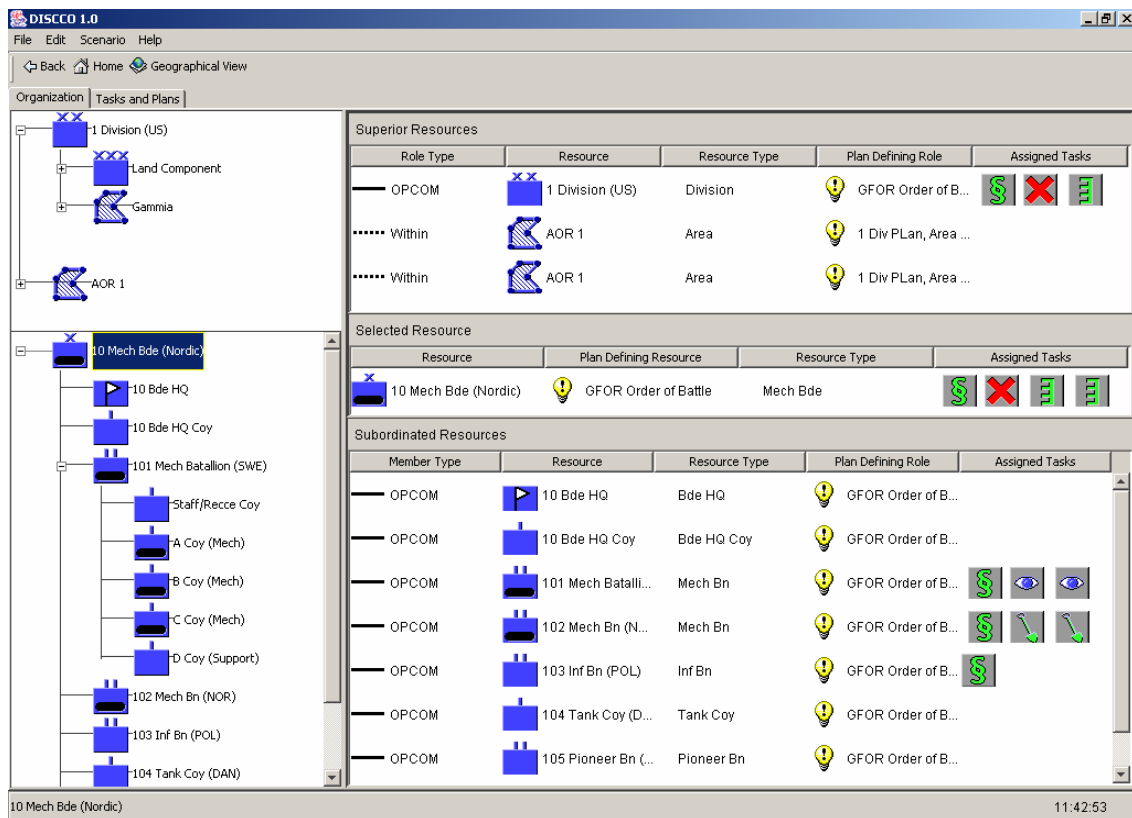


Figure 8.1. An organization tree view depicting the superior and subordinated roles of the 10. Mechanized Brigade.

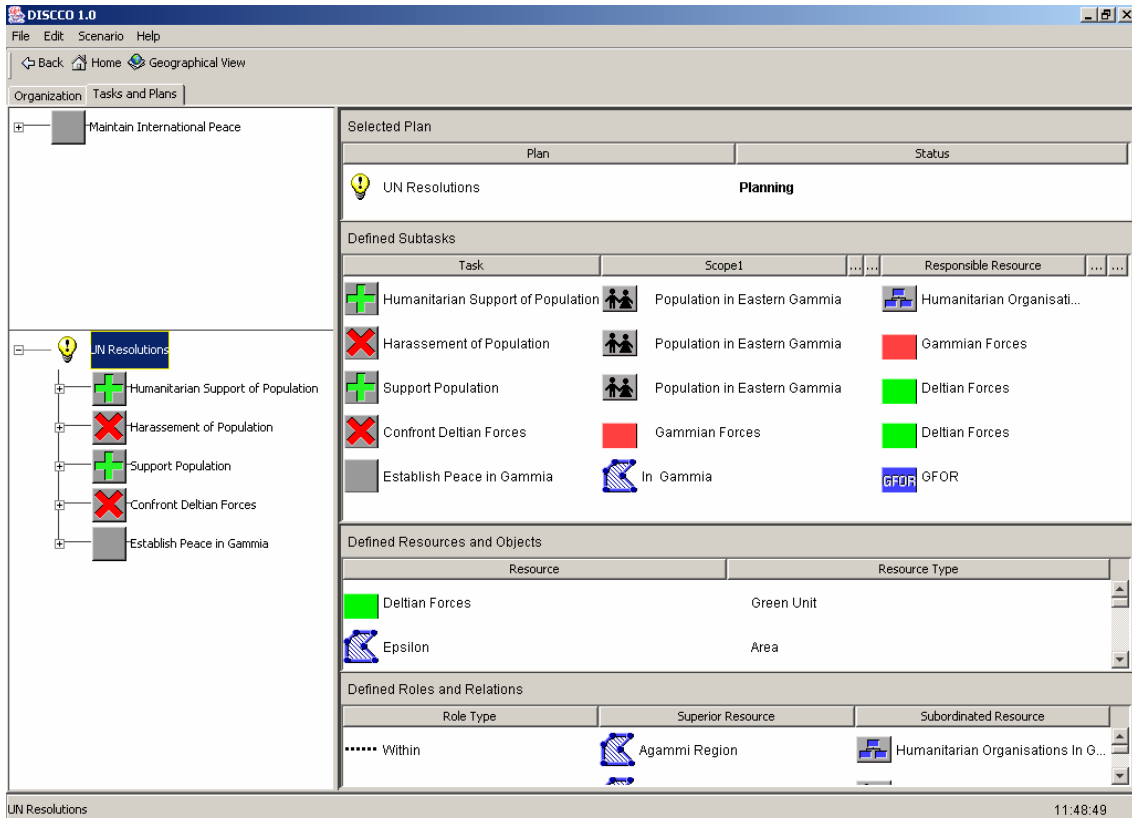


Figure 8.2. A plan view defining the situation in Gammia, and the main task for the U.N. operation.

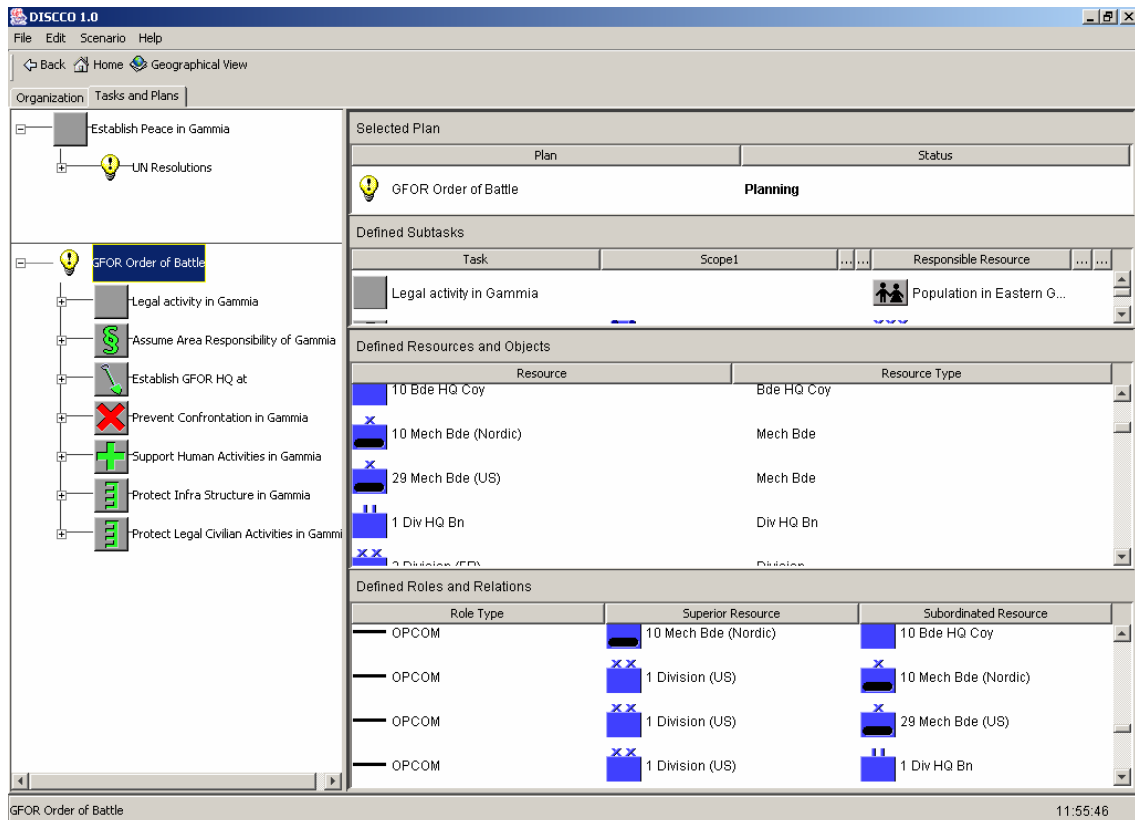


Figure 8.3. A plan view depicting the GFOR Order of Battle.

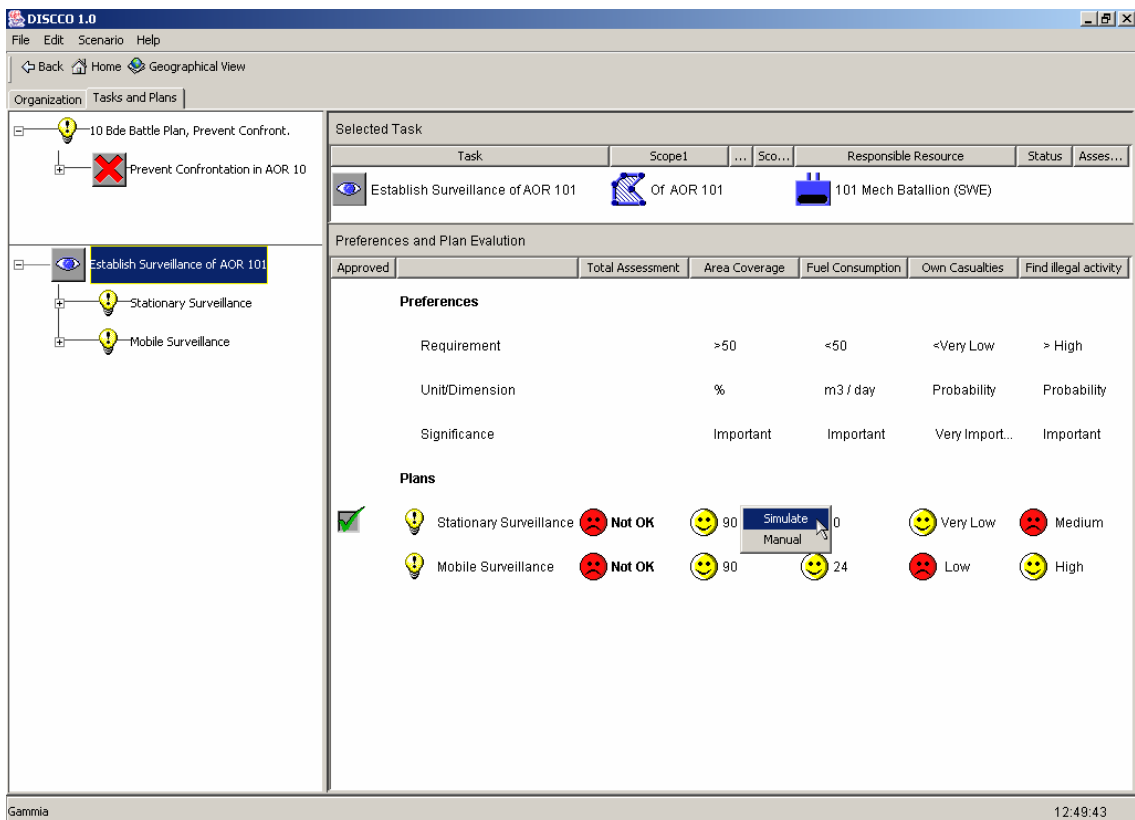


Figure 8.4. A task view depicting the potential solutions on how to establish surveillance of a certain area.

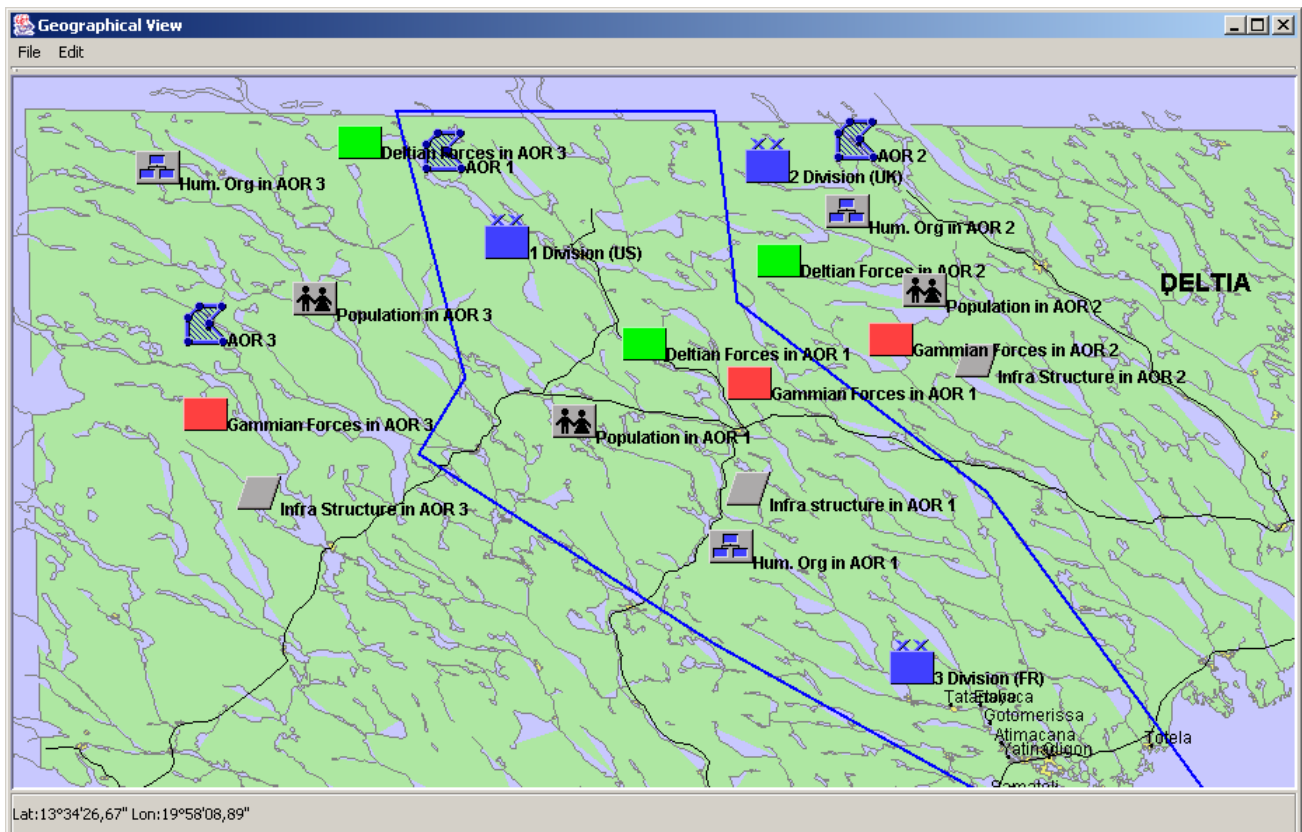


Figure 8.5. High-level forces and other entities of different affiliations are depicted in a geographical view.

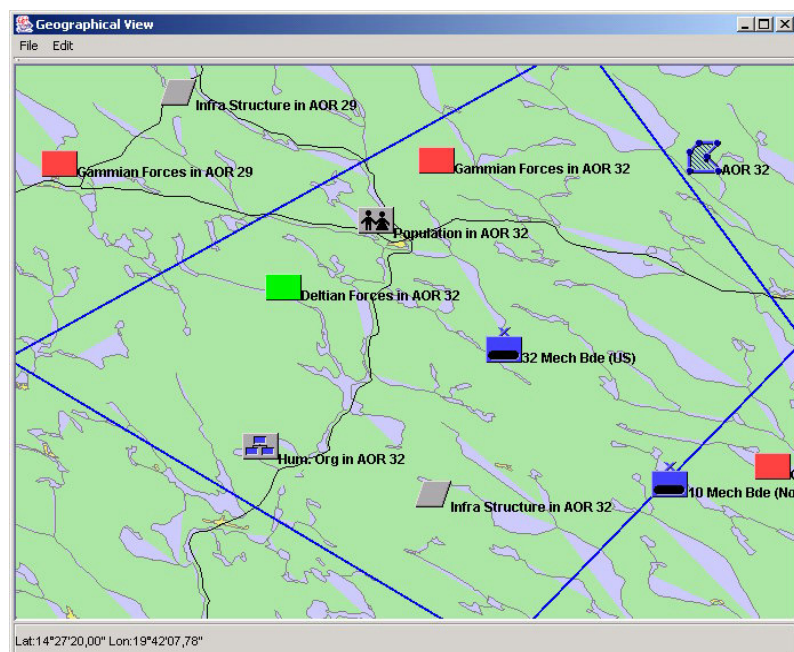


Figure 8.6. Zoomed in, the geographical view depicts forces and other entities on a lower level of abstraction.



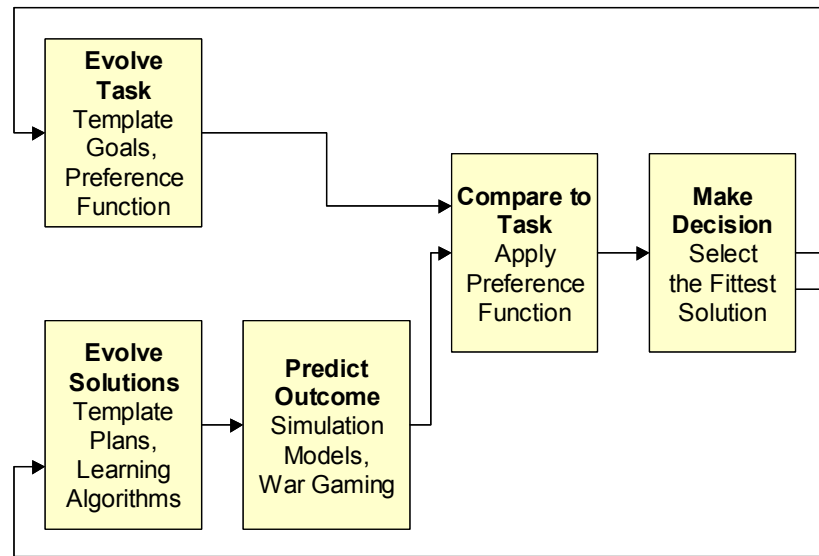


Figure 8.7. Tools supporting the generic decision-making process.

## 8.3 Decision Support

### Supporting the Generic Decision-Making Process

In Section 7.2, we suggested that the generic decision-making process depicted in Figure 7.1 represents all decision-making in the C2 context. Hence, it would be of great interest to design the technical support tools based on this process. Providing automated tools that support each of the different stages in the process will hence keep the work performed by computers open for interaction. Also, as the different stages can be automated to a various extent, the cognitive work can be delegated to computers when the commanders trust the automated support and when admitted by the current stage of technological development.

Consequently, Figure 8.7 suggests different technical tools and techniques to support each of the different stages in the generic decision-making process. As indicated in Figure 8.4, some examples of Decision Support integrated with the Command Support tools have been implemented in DISCCO 1.0. Hence, following the decision-making process, the screen-shot in the figure depicts the

definition of the task to establish surveillance of a certain area, according to preferences in different attributes. As mentioned in Section 8.2, two alternative solutions have been developed: ‘Stationary Surveillance’, and ‘Mobile Surveillance’. The consequences of these plans have been predicted by a mixture of manual and automated assessments and, in turn, have been compared to the preferences. Hence, the currently approved plan, ‘Stationary Surveillance’, is considered not being sufficient regarding the probability to detect illegal activity, whereas the other plan, ‘Mobile Surveillance’, implies a risk exposure for own casualties. Since, according to these current assessments, neither of the plans is expected to fulfill the goals of the task, the approval of the first plan has to be reconsidered, and further evolvement of either the task, or any of the plans, is needed.

In the following sections, the implementation of these different decision support tools will be discussed.

## **Evolving the Task**

Since a task expresses the demand from a higher decision level, the hierarchy of decided tasks in the organization constitutes a model of utility. Consequently, there is no explicit value, positive or negative, of anything that happens unless mentioned in the goals and restrictions of the task. Hence, the Decision Support must carefully facilitate a structured formulation of tasks. Also, as mentioned in Section 8.1, this should be complemented with unstructured multi-media objects to allow a richer formulation of the intents to, in turn, reduce the residual between tacit expectations and the explicit utility model.

The structured formulation of tasks is constituted by goals and constraints in different aspects. These *attributes* may be represented by a *multi-attributed preference function*. A definition of such a function, conforming to decision theory with multiple objectives as discussed in Section 4.1, is described in [Brynielsson and Wallenius, 2003], and [Huang *et. al.*, 2003]. This function may represent goals in different attributes, which in turn express the utility of the consequences of different plans.

The set of different attributes for a certain task may be set arbitrarily, depending on the judgment of the decision-maker. There may however be templates defined for different task types, representing

typical sets of attributes. To further promote the mixing of computer supported assessments with human assessments, goals in some attributes may be represented by numerical values, representing well defined measures of phenomena in the consequence domain, whereas other goals may be represented by less defined scales, such as {'high', 'medium', 'low'}.

Among the different decision-rules dealing with multiple objectives listed in Section 4.1, we argue that it is the conjunctive rule that primarily applies to the goal driven decision-making in C2. Using this rule implies that a solution should be selected if it is better than the goal for each attribute. There should, however, be possible to distinguish between alternatives also when more than one of them, or neither of them, are expected to fulfill all goals. Hence, the importance of different attributes may be represented in the preference function, supporting also the lexicographic rule.

Also, the extent to which the goals are fulfilled or, rather, to which extent they are compromised, should be possible to represent in the preference function. Consequently, the following classification scheme for ranking possible outcomes in different attributes may be considered:

- the outcome will be in accordance with the goals (*Ok*)
- the goals will not be fulfilled (*Compromised*)
- the outcome will be disastrous (*Severe*)

See [Brynielsson and Wallenius, 2003] for the mathematical definition of such a preference function and for further discussion on the decision-rules.

## **Evolving Solutions**

A solution to a task is, according to the model, expressed by a plan. In turn, this plan represents tasks, assignments and organization on a lower decision level. To facilitate the evolvement of such plans, there will be means to provide templates representing common solutions to a task type. As the starting point for the decision-maker when developing the solution, these templates will have predefined tasks on

the lower level. Through the Task Type class, admitting definition of services, there may also be support to list resources that are allowed to be assigned to a certain task. In addition, potential targets for a task, represented by ‘affected tasks’ and ‘affected resources’, may be listed to support the decision-maker.

Other support tools, based on different AI techniques, may automatically suggest and evolve plans based on information on the current situation. Again, such automatic handling is complementary to the human cognitive ability. Hence, automatically developed plans should be exposed to evaluation and further development in a manual manner. The architecture of the system, with the separation between Command Support and Decision Support, should facilitate development of such AI-based support tools, although we have currently no further suggestions on how these should be constituted.

## Predicting the Outcome

The assessment of solutions includes simulating how the situation will unfold, given that the different solutions are applied. Such prediction of the consequences of solutions is, according to Section 4.2, an act of induction. During a natural decision-making process, the simulation is performed simply by the imagination of what will happen if the solution is executed, utilizing mental models that capture previously acquired knowledge.

There are several manual methods to externalize the mental simulation, in order to improve the quality of the prediction, and to make it more efficient. In the case of interdependent actors, i.e., when there is an adversary, *game playing* can be used to perform the simulation. Hence, one or several persons can be assigned to simulate the decision-making of the adversary forces. The evolvement of the situation is then discovered using more or less elaborated methodology and support.

*GECCO* (Game Environment for Command and Control Operations) is a generic concept used to realize different *micro-worlds* [Brynielsson and Wallenius, 2001]. In *GECCO*, a game server hosts a simulation of different units moving on a map. The units belong to players affiliated to different teams, see Figure 8.8. Controlled by their owners, the units may interact with each other and with an automaton matrix



representing the environment, as depicted in Figure 8.9. Hence, the units may observe and affect the situation constituted by the states of the different units and the environment. The information on observed states is shared among players belonging to the same team.

By these means, game scenarios of rather different characters may be realized. Figure 8.10 depicts a World War II-scenario. Other scenarios that have been developed include a fire fighter game, in which the players are to engage units to fight a spreading forest fire, and a rescue mission game, saving persons in the water by a collapsing bridge. Provided as open source software, GECCO is mainly suited for C2 research. It has, e.g., been used for studying the implications of information superiority [Kuylenstierna *et al.*, 2003].

We argue that a concept similar to GECCO can be developed to support gaming for decision-making purposes as well. Thus, the simulation should be integrated with the command support, as previously mentioned. To this end, it must be possible to generate copies of the Common Situation Model, i.e., plans depicting sets of resources, plans, and tasks, into the simulated domain. [Huang *et al.*, 2003] suggests how this can be achieved by the generation of *agent assemblies* representing the behavior of resource hierarchies.

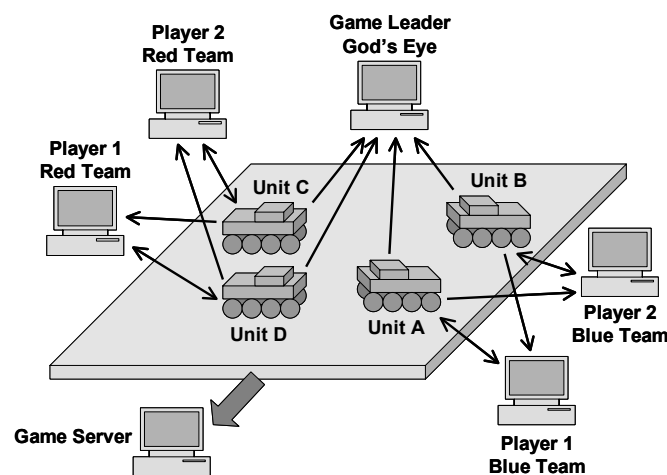


Figure 8.8. In GECCO, the players, belonging to different teams, control units whose performance and interaction is simulated in the game server.

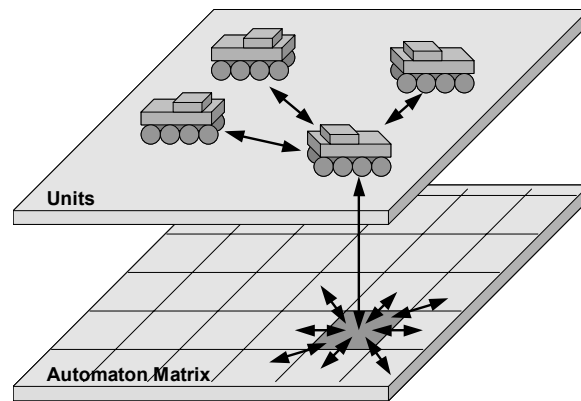


Figure 8.9. The units in GECCO interact with each other's internal states and with an automaton matrix, representing the environment.

The resulting simulation is primarily automated regarding physical behavior, by including simulation models depicting typical abilities such as sensor ranges, transport speeds, and effects from weapons, while still letting the human players perform the decision-making for the simulated forces. However, to decrease the need for human interaction, and thus save time and human labor, it would be of interest to automate the simulation also of the decision-making aspect. Consequently, the decision-making for the adversary forces, but also for the own, subordinated, units should be simulated.

One way of implementing agents with the ability to make decisions is to apply very simple decision rules. To this end, [Ilachinski, 1997] and [Woodcock *et. al.*, 1993] both reduce the decision-making problem into a small set of parameters representing the *personality* of the agent, including the ability to move towards alive or injured, friendly or hostile, agents respectively. The problem of this approach, as we argue, is that the relation between this set of parameters and the behavior of real forces is uncertain. In other words, we need means to understand to what extent the simulation model corresponds to the real world.

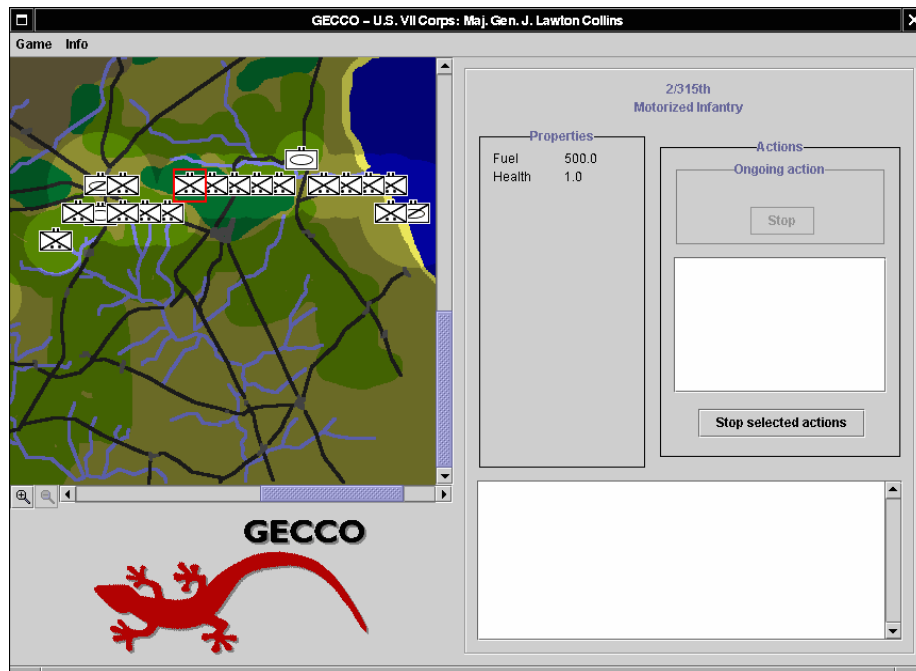


Figure 8.10. GECCO with a World War II scenario.

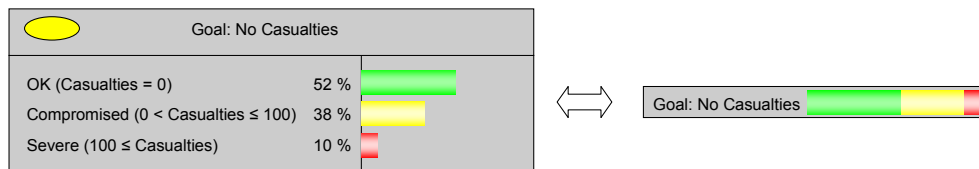


Figure 8.11. A chance node depicting the probability to achieve the goal 'No Casualties' along with the corresponding 'probabar'.



At the other end of the scale, the decision-making of the simulated forces is modeled just as accurately as the decision-making to be supported by the simulation. Hence, a simulated decision-maker would behave according to a model as complex as indicated in Figure 8.7, utilizing automatic support tools in all steps. Regardless whether it is exactly this model that will be used or not, simulating human decision-making in a completely realistic manner is a very difficult task, equivalent with replacing real decision-makers with the design of fully automated decisions.

However, according to Bayesian decision-theory (see Section 4.1), it is both possible and necessary to make decisions based also on uncertain information. Hence, incomplete models may be utilized to perform induction, under the condition that the assessment of this incompleteness is part of the analysis. Thus, both the uncertainty in the models and the uncertainty in the results of the simulation should be included in the development of simulation-based Decision Support.

The technique of *Bayesian Networks* [Russell and Norvig, 2003] may be applied to represent uncertain causal dependencies and Bayesian inference from observations. [Suzić, 2003] and [Runqvist, 2004] both use this concept to estimate the intentions of the enemy in C2 applications, giving a probability distribution over the different possible intentions. By deploying Bayesian Networks, the situation can be described by *joint probability density functions*. In turn, these are described by *conditional probability tables*, each representing the probability of a certain effect to occur, given that a potential combination of actions is executed.

Influence Diagrams is a generalization of Bayesian Networks, also incorporating means to model the expected utility caused by decisions through chains of probabilistic causal relationships [Russell and Norvig, 2003]. Consequently, a rich and transparent model of effects caused by actions can be expressed by this generalization, greatly facilitating predictive and uncertainty based situation awareness [Suzić and Wallenius, 2005].

One problem with Influence Diagrams is that it is very cumbersome to fill in the causal relationships represented by the conditional probability tables in a manual fashion. Instead this can be dealt with

by using *agent-based Monte Carlo simulations* to retrieve the probability distributions of effects given different combinations of actions. These distributions are described by samples of possible states represented by sets of *particles*. The use of such particles as a basis for decision-making has been investigated by [Johansson and Suzić, 2005]. The application of particle-based Monte Carlo Simulations for predictive purposes has been described by [Brynielsson *et. al.*, 2005], and by [Johansson and Suzić, 2005], while the connection with Influence Diagrams has been developed by [Suzić and Wallenius, 2005].

In conclusion, prediction of the consequences of potential solutions should be based on a mix of mental and computer-based models, managed in a coherent manner. Applying Influence Diagrams will provide such a framework, and are also capable of managing uncertainty in both models and information.

## Comparing to the Task

In the case when the decisions are independent of the decisions of other actors, the comparison to the task is quite straightforward. The consequences must be measured in the dimensions given by the different attributes. After that, the preference function is applied to evaluate these consequences according to the goals, and hence rank the different alternative solutions. The uncertainty of the predicted consequences should however also be regarded to include risk estimation in the decision-making. Again, Influence Diagrams provide the necessary framework for this.

In order to be informative, Influence Diagrams however tend to grow and get very complex. Also, it may be difficult for decision-makers to relate to the probability distributions presented in the diagrams. An attempt to aggregate the information from an influence diagram, and to make it more comprehensible, is depicted in Figure 8.11. The main idea behind this human-machine interface is to relate the predicted consequences of decisions to the goals of the stated task, i.e., the preference function. Hence, the information pieces in the plan regarding mission objectives, situation, tasks and directives directly refer to chance nodes in an underlying Influence Diagram. The assessed outcome may then be presented in accordance with the

classification scheme as was discussed in the section on ‘Evolving the Task’, above.

On the left in Figure 8.11, a chance node depicts the probability that the outcome will take any of three states, inline with this scheme:

- The outcome will be ‘OK’ (no casualties).
- The outcome will be ‘Compromised’ (more than zero casualties).
- The outcome will be ‘Severe’ (more than 100 casualties).

Since the probabilities for each class of outcomes always will sum up to 1, it is possible to present a rough indication of the relations between the probabilities in a more compact manner. To this end, the concept of *probabars* is introduced on the right in Figure 8.11. Applying a color scheme corresponding to the classification of outcomes, e.g., ‘Green’ for ‘OK’, ‘Yellow’ for ‘Compromised’, and ‘Red’ for ‘Severe’, will give a quick understanding of the expected outcome compared to the mission requirements. A fully green bar means that there is a probability of almost 100 % that the outcome will fulfill the requirements. A yellow part in the bar indicates that there is some probability for an unacceptable outcome, representing a risk that still may be reasonable to accept. However, if a red part is visible, there is a substantial probability of a disastrous outcome, which hence represents a risk that may be unreasonable to accept.

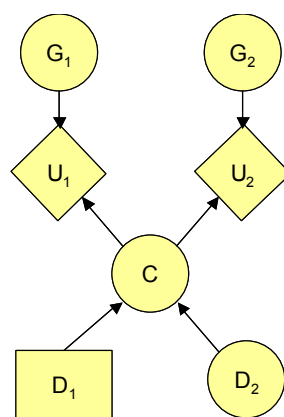


Figure 8.12. An Influence Diagram depicting the dependencies of two agents' decisions in the C2 case [Brynielsson and Arnborg, 2004].

The above approach is based on a prediction of the enemy's performance without taking into account that own decisions and the opponent's decision depend upon each other. [Brynielsson and Arnborg, 2004] go further and use Influence Diagrams to model the dependencies between the own decisions and the opponent's decisions, as indicated in Figure 8.12. This diagram describes the situation from Agent<sub>1</sub>'s perspective. Hence, a decision node,  $D_1$ , represents Agent<sub>1</sub>'s decisions, while a chance node,  $D_2$ , models Agent<sub>2</sub>'s decisions. The consequences,  $C$ , depend on the decisions of both agents. Finally, the Agent<sub>1</sub>'s utility,  $U_1$ , depends on its goals,  $G_1$ , and the consequences, while Agent<sub>2</sub>'s utility,  $U_2$ , depends on the goals,  $G_2$ , and, again, the common consequences.

According to this view, all information is uncertain, including the belief on the enemy's decisions and goals, and the belief of the consequences of different decisions. The consequence node  $C$  represents the probabilities of different consequences conditioned by different combinations of decisions,  $D_1$  and  $D_2$ . Estimating these probabilities correspond to the prediction of outcome discussed in the previous section. This means that each possible combination of decisions needs to be simulated to identify the best own decision.

Approaching the problem to capture the dependencies between the decisions of two agents', *Bayesian Games* can be applied [Brynielsson, 2004], [Brynielsson and Arnborg, 2004], [Brynielsson and Arnborg, 2005], and [Brynielsson and Arnborg, 2006]. This approach can be applied to model agents' beliefs of other agents' beliefs, and then derive probable decisions of the opponent together with the best decision, or decisions, regarding own actions. By letting the commanders maintain a belief over several possible opponent models, the Bayesian game technique seems feasible for capturing dependencies between uncertain decisions among opposing forces.

## Making the Decision

Given that the different alternative solutions have been ranked according to predicted consequences and the preference function, the actual decision is reduced to a trivial selection of the best solution. Consequently, if all the different stages of the decision process were entirely automated, the complete decision loop in Figure 8.7 would



represent a completely autonomous process. However, this would require that there were essentially no tacit expectations besides those represented by the preference function, that all possible decision alternatives were represented, and that the consequences can be accurately predicted for all the different attributes. As such completeness of the models is almost unreachable, the decision-maker is responsible for that, at least, the most important aspects have been considered in the analysis.

Decisions must also be made on the set of potential solutions that should be the subject for further analysis. Hence, it must be decided which potential solutions that should be kept for future consideration and which can be eliminated. Also, if the analysis shows that the task is too difficult, a change of goals need to be considered.

Altogether, we argue that the complexity of all these different aspects implies that the actual decision should not be made automatically, but left for the human decision-maker, unless for well-defined and extremely time critical problems.



## Chapter 9

# Three Applications

To further concretize the concepts of DISCCO, as presented in Chapter 8, and to ensure its applicability, we will present the results of three studies providing different examples of applications.

A scenario developed at Saab Systems provides the base for all three studies. In this example, the governing majority of the fictive country of Gammia has launched a full-scale military ethnic cleansing operation towards the minority Milli population. This has triggered a subsequent invasion of parts of Gammia by the neighboring Deltians, who belong to the same ethnic group as the Milli people. After several months of discussions, the UNSC mandated a UN peace enforcement mission, the Gammia Force (GFOR), and requested troop contributions from several UN member nations, among them the USA and the major EU nations, including Sweden. Part of the Land Component is the 1 Division, of which the 10 Mechanized Brigade consists of force contributions from the Nordic nations. The 101 Mechanized Battalion is however entirely Swedish [Saab Systems, 2002].

Hence, the first study deals with how to support the work of a battalion commander in establishing surveillance of the Area of Responsibility. On site in Gammia, and assisted by the members of the staff, there is a time frame of a few days to perform this planning in dedicated staff meeting rooms.

The second study deals with the preparation of the defense against nuclear, biological and chemical threats (NBC) to the Swedish contribution to the international operation. This planning work is performed by members of the Joint Forces Command, who are decision-makers working in a normal office environment and have got a couple of weeks to perform the planning. In particular, the emphasis in this case is on the analysis of the effects of different decisions to

decrease the risk of casualties related to NBC without superseding the budgetary constraints.

The third study deals with a riot control mission at a summit in one of the major cities in the region. During the execution of the mission, the tactical commander has a few minutes up to some hours to make the necessary decisions. These decisions regard how to protect the meeting delegates, the population, and the peaceful protesters, against hostile rioters.

Each of these examples deals with a certain class of decision-making, in line with the classification discussed in Section 2.3. Hence, together they cover a broad spectrum of C2 cases, with time frames spanning from minutes to months, and within different work environments, as showed in Figure 9.1. All the examples are effects-based since they emphasize what effects to expect of potential actions in different domains. They however deal with risks and uncertainty in slightly different manners. They also use different methods to predict the effects, including a mix between mental simulation and simple prediction models, simulation of complex human behavior using agent-based approaches, and applying domain specific services to perform the prediction.



Figure 9.1. The three applications classified according to the different cases of decision-making defined in Section 2.3.

As a result, these three studies indicate the versatility of the generic DISCCO concept. They however also reveal some weaknesses in the current stage of development, in particular regarding how to present the information to the decision-makers in a useful manner. Thus, major challenges remain to develop a full scale concept that can be used in real settings.

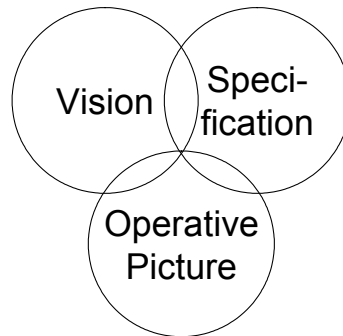


Figure 9.2. The three levels of abstraction in the design process, according to [Löwgren and Stolterman, 1998].

## 9.1 The Design Process

The three applications of DISCCO presented in this chapter provide examples of Human-Computer Interaction (HCI). The research on this subject is a large field of its own, with a number of theories and methods [Löwgren, 1993]. Since there is a broad scope of this thesis in dealing with both technical and human issues, and with the emphasis more on the technical side, it has not been possible to perform a full scale HCI research project. Yet, the applicability of the developed concept has been increased by involving different domain experts in the design process. The evidence for the applicability in different domains is thus provided by revealing details on the design process and how the reference persons were involved.

According to [Löwgren and Stolterman, 1998], the work of designing IT artifacts deals with three levels of abstraction interacting with each other in a dynamic process, as indicated by Figure 9.2. This design process begins once the designer encounters, or even starts to think about, the *design situation* – the situation which the designed artifact is to support. When investigating this situation, the designer very soon

conjures a *vision*, or the organizing principle, of the artifact. The next step is that the designer develops an *operative picture* to concretize this vision. The concretization continues successively by encountering both the vision and the design situation. During this dialectic process, both the operative picture and the vision will need to be changed. At some point, the operative picture gets worked out in such detail that it can perform as a *specification* for the construction process. However, the design work still continues, as new problems, requirements, and opportunities will show up. Our work deals with the first part of this design process, developing the vision, as presented in Chapter 8, and the operative pictures, here denoted *prototypes*, represented mainly by illustrations of how the support tools will appear to the users.

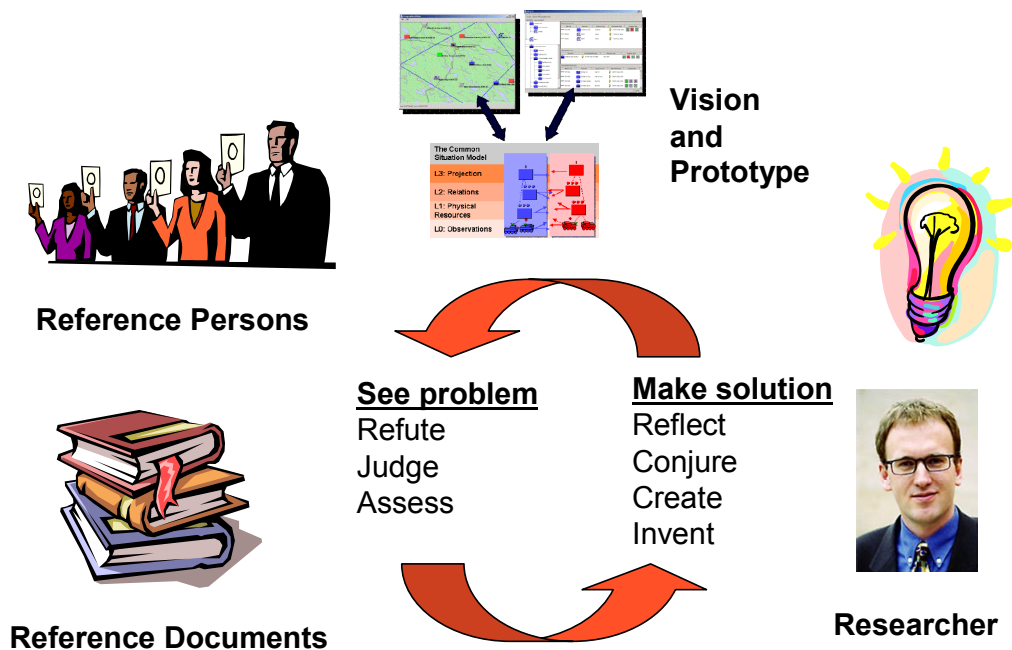


Figure 9.3. The design process applied in the development of the three applications.

The dynamic design process we have applied in the development of the three applications is depicted in Figure 9.3. This process is comparable to the conjecture and refutation process discussed in Section 4.2. Based on previous experiences and findings, the researcher tries to understand the kind of work performed, and to invent technical services as a solution to support this work. Along with the vision of the design solution, a prototype is developed to be

presented to people experienced in the area. Consequently, domain knowledge is captured by retrieving qualitative feedback from these reference persons pointing out weaknesses of the solution and proposing improvements. Also, the reference persons make suggestions and comment on different documents that describe the supported work. We argue that this method is scalable since it will produce a prototype that successively will become more applicable depending on the amount of feedback retrieved from the increasing range of reference persons.

In the following sections, presenting the results of the three studies, we will describe in more detail how the reference persons have been involved. The first study, on establishing surveillance, has involved two reference persons, the second study, dealing with NBC Defense, has involved three reference persons, while the third study, on riot control, has not involved any reference persons.

For each study, we will give a brief presentation of the reference persons, the key reference documents that have provided input and feedback, and how they were involved further in the process. Then we will describe the kind of work supported, and the proposed solution in different aspects, before the presentation of remaining conclusions.

## **9.2 Planning of Tactical Operations: Establish Surveillance**

### **Background**

The first study was carried out as an internally funded development project at Saab Systems, with the volume of approximately 1000 work hours over a period of around 4 months. The purpose of the project included that the ideas of a DISCCO concept, as presented in Chapter 8, was going to be further developed by designing a prototype.

### **The Design Process**

Except from the development team and the researcher, the project involved two domain experts acting as reference persons:

- Reference person *A* had previously been employed to model the planning processes at the Joint Operative Level of the armed forces. At the time of the study, he was working with developing support systems for the same area.
- Reference person *B* was, at the time of the study, working with defining and marketing support systems for ground forces, thus having experiences from working in close contact with the customers of such systems.

These two persons were engaged according to the following items:

- During the initial project meetings, and based on preliminary sketches, the focus of the prototype was discussed with *A* and *B*. It was then agreed to emphasize the planning of tactical operations during an international operation. Also it was agreed that the example should deal with how to establish surveillance of an area, since such an example could easily involve simulation-based support.
- *A* was then responsible for developing a realistic background material to provide the contents of the prototype, and to facilitate the understanding of the work performed at a battalion staff. He thus provided the background scenario for the fictive UN peace enforcement mission mentioned in the introduction of this chapter [Saab Systems, 2002]. He also developed a Force Listing [Saab Systems, 2002a] and an extract of a Brigade Battle Plan [Saab Systems, 2002b] (see Figure 9.4).
- During the implementation of the prototype, both *A* and *B* were engaged in providing feedback to the appearance of the user interface. This feedback was retrieved during demo-sessions performed in a normal office environment.
- Also, *A* was engaged to discuss in detail how the Brigade Battle Plan was to be interpreted in terms of the ontology presented in Chapter 7.

The result of the project became the DISCCO 1.0 demonstrator. As this prototype, to some extent, has already been presented in Chapter 8 this section we will provide some further details from the user's perspective.



*Extract from 10th Brigade Combat plan 190800Z AUG 06*

**Mission**

10 Brigade shall prevent confrontation between the belligerent parties in the eastern parts of 1 Division's AOR, support humanitarian aid activities within the area, protect infrastructure and legal civilian activities, and...

**Deployment and tasks**

**101 battalion**

AOR is delimited by straight lines between coordinates 7040/1640 - 7030/1645 - 7015/1630 - 7020/1620 - 7025/1620

establish command post and camp at ATAMACANA

establish surveillance of AOR

check traffic on bridges over GOMOTASSE RIVER, on the roads along the GOMOTASSE, and on the GRAFASH road from YATINAC for contraband materiel and persons on the ICPFG wanted list

search, seize, and destroy illegal weapons and other contraband materiel

clear mines and UXO prioritising roads and residential areas

protect the radio station and water tower in ATAMACANA, the ICRC headquarters in GOMOTERISSA, ....

support the ICRC, UNHCR and UNHCHR with transports and if necessary escort

liaise with the ICPFG concerning common order and crime prevention

be prepared to receive parts or all of 104 armd coy

be prepared to receive mine clearance team from 105 bn (pioneers)

be prepared to detach one mech coy in current disposition to neighbouring battalions within 24 hours from order

Figure 9.4. A fictive extract from a brigade combat plan defining the tasks for the commander of the 101 Battalion [Saab Systems, 2002].

## The Work Supported

The work of the commander and the staff of the Swedish 101 Mech. Battalion is defined and restricted by a number of documents, including the UNSC mandate along with plans, orders and regulations on different levels. Among these, the Brigade Combat Plan depicted in Figure 9.4 provides the most essential information.

According to this plan, the commander of the 101 Battalion is accountable for a number of tasks related to the Area of Responsibility (AOR). Supported by the staff, the commander has a few days to prepare for how to solve these tasks.

In particular, the study concentrated on how to plan for one of the tasks, 'Establish Surveillance of AOR'. As mentioned in Section 8.2 and 8.3, two main decision alternatives seem reasonable to solve this

task: ‘Stationary Surveillance’, establishing fixed observation posts, and ‘Mobile Surveillance’, patrolling the roads in the area. A number of constraints may be regarded when selecting which alternative that is most favorable. In this case the safety of own forces is prioritized above the probability of identifying illegal activities in the area. The fuel consumption is also considered being a limiting factor when making this decision, along with the size of the area covered by the surveillance.

## **The Proposed Solution**

As seen in Figure 9.4, the combat plan in text format is described in a rather formalized manner. According to the plan, the battalion is responsible for tasks of different types. Such possible task types can be listed as capabilities when preparing the units before utilizing them for particular missions. As further defined in the battle plan, the tasks refer to other objects involved in the situation, including other units and organizations, certain areas and places, etc. During the study, it was showed that the ontology defined in Chapter 7 indeed can be applied for representing the tasks and resources defined in the battle plan and in superior plans. Hence, a Common Situation Model was developed according to the principles discussed in Section 8.1, using a database based on commercial software.

When performing the planning work, the set of Command Support services described in Section 8.2 are held available to the commander and the staff. Hence, through the different views, the decision-makers have access to the situation model representing all documents describing the situation and defining their work.

To this end, the task to establish surveillance is defined in a task view, according to Figure 8.4. To represent the goals for the task the preference function, including the different attributes and their corresponding thresholds and priority factors, is set up using this interface. Also according to Figure 8.4, two potential plans representing the main decision alternatives have been defined. Before they can be evaluated according to the preference function, these two plans need to be developed in some detail, such as where to establish surveillance posts and which roads to patrol.

The prediction of the different attributes is then performed as a mix between manual and computer based simulation. Since the attributes 'Own Casualties' and 'Find Illegal Activities' are difficult to simulate automatically, and also are difficult to put numbers on, they are subject for manual prediction. It is much easier to come up with straight forward simulation models predicting the attributes 'Fuel Consumption' and 'Area Coverage', which thus are predicted automatically.

## Conclusions

By this study we conclude that it, indeed, is possible to design a framework of command and decision support services as drawn up in Chapter 8. The ontology described in Chapter 7 suits well to represent different documents describing the situation and the tasks for a decision-maker working in this timeframe. It was also shown how mental simulation combined with rather simple automated simulation models can be used to predict the consequences of different decision-models.

However, we also conclude that the applied method to represent the preference function is inadequate in dealing with uncertainty. For example, the uncertain numbers of casualties among own forces, and the maximum risk that can be tolerated, need to be addressed using probabilities. In the implementation of the preference function, this was awkwardly represented by setting the requirement for casualties to 'very low probability' and by setting the significance of this attribute to 'very important' (see Figure 8.4.).

A better approach to deal with risks may be to state different degrees of goal satisfaction, such as 'Ok', 'Compromised' and 'Severe', and then estimate the probability for these levels to occur separately. This can be done by use of 'probabars', as discussed in section 8.3. In the following two studies, it was investigated whether such an approach would be more applicable.

## 9.3 Planning of Joint Operations: NBC Defense

### Background

This study has been carried out in collaboration between the Swedish Defense Administration (FMV) and the Royal Institute of Technology during a period of six months.

The main purpose of this study was to investigate the extent to which the DISCCO concept could facilitate the work of NBC Defense. As FMV is currently responsible for developing a service based command support system demonstrator for the NBC area supported by the Swedish Defence Research Agency (FOI), the work was to emphasis the relations to this NBC Demonstrator.

### The Design Process

Except from the researcher, the project involved three domain experts acting as reference persons:

- Reference person *C* has a background in chemical engineering. Responsible at FMV for development and procurement of technology related to NBC defense, he is particularly involved in the development of the demonstrator mentioned above.
- Reference person *D* is a military officer, working at the Swedish Armed Forces with the development of NBC Defense services.
- Reference person *E* is a military officer in the Swedish Armed Forces. He is responsible for planning of NBC Defense at the Joint Forces Command.

These persons were engaged in the development process by a set of meetings, all, but one, arranged in *C*'s office at FMV. In total, seven meetings, each for the duration of between two and three hours, were executed according to the following items:

- During the first three meetings, *C* and *D* were involved in defining the scope of the study. To this end, they described the plans for the future organization and technical support of NBC Defence. They also provided sources of written information, including the NATO's Doctrine for NBC Defense [NATO, 2003], an authentic operation plan for the Swedish contribution to EU's operation in Bosnia [Swedish Armed Forces, 2004], and a report on the ongoing work to design NBC related decision support services [FOI, 2004]. After the presentation of the DISCCO concept and the DISCCO 1.0 prototype, as developed in the study presented in Section 9.2, it was agreed that the emphasis should be on planning of the NBC Defense at the joint operative level. Thus, the DISCCO 1.0 demonstrator was to be updated with input from the operation plan to see whether it was possible to apply the ontology with this kind of information.
- During the subsequent three meetings, these updates were discussed with *C*. It was then identified that the model was insufficient to represent the causal relationships between means in the NBC area and desired effects. To better support these relationships, the application of Influence Diagrams was suggested by the researcher. *C* found this interesting and pointed out that this area should be of particular relevance to the future development of DISCCO. *C* also asked about the relations between DISCCO and other support tools in the NBC area. It was commonly agreed that DISCCO represented services related to general C2 issues, irrespective of the managed domain, while, e.g., the NBC demonstrator deals with domain specific details.
- At the final meeting, the results of the study were presented to *E*. He then responded that there indeed were many interesting features in the concept, such as the support for graphical planning and the support for analyzing the effects of actions. However, he also maintained that there should be much more emphasis in adapting to current procedures at the Joint Forces Command.

## The Work Supported

The application developed in this study deals with preparing the contribution of Swedish forces to a peace-keeping operation mandated by the U.N. Among the many issues that need to be planned for, NBC defense is particularly important. NATO defines NBC defense as [NATO, 2003]:

*...all measures designed to defend against attacks with nuclear, biological, chemical and radiological weapons or the hazards arising from Release Other Than Attack.*

Within the Swedish Armed Forces, the Joint Forces Command (OPIL) is responsible for preparing the force contribution to a U.N. operation. Within OPIL, the staff department for deliberate planning (J5) is responsible for the planning of this preparation, supported by other departments in the staff. The result of the planning is the *operation plan*, in which the NBC issues are stated in Annex U, *Operations in an NBC Weapons Environment*. Among other contents, this annex mainly includes [Swedish Armed Forces, 2004]:

- The declaration of the mission for the NBC operations.
- A situation description in terms of threats in the operation's area.
- Stated tasks and directives for the force contribution.

According to our fictive example, reconnaissance has shown that, among other NBC related threats, there is a chemical factory in the area that may be subject for an attack from hostile forces. If such an attack is carried out, there will potentially be a toxic release threatening own forces and the population. Thus, measures should be taken to reduce this risk of negative effects. Potential measures to perform include (among other alternatives) [NATO, 2003]:

- Protecting the plant from attack.
- Preparing a signal system to be able to warn and evacuate people.
- Preparing for *Collective Protection* (COLPRO) of own forces.

However, each of these measures is connected with a cost in terms of an increased requirement of personnel. Thus, there is a trade-off between increased safety and keeping within the budgetary constraints. According to our interpretation of EBO (see Section 2.2), this trade-off is exactly what it is all about – a careful consideration of the uncertain causal relations between actions and probable effects when making decisions.

Technical services supporting NBC Defense are currently under development for the Swedish Armed Forces [FOI, 2004] [Rejnuš *et al.*, 2004]. These include, among others:

- Surveillance, indication and warning services.
- Prediction support services based on dispersion models.
- An information warehouse.
- A report management service.

These services, however essential to NBC Defense, need to be put in the context of more general C2 issues and EBO, as discussed throughout this thesis. Consequently, services, such as offered by DISCCO, are required to support the above consideration about conflicting goals by means of Decision Support, and to support the communication of decisions, by means of Command Support.

## The Proposed Solution

In Figure 9.5, a set of decision support services are depicted to facilitate the assessment of potential decisions regarding NBC Defense. These services are integrated with command support services keeping track of the contents of the operation plan, i.e., mission priorities stated by the superior command, and tasks and directives for the forces.

As indicated in Figure 9.5, and as described in Section 8.3, an Influence Diagram is used to represent a model of the causalities, and hence to express the relations between what is stated in the mission and the decisions that may be made on how to achieve this.

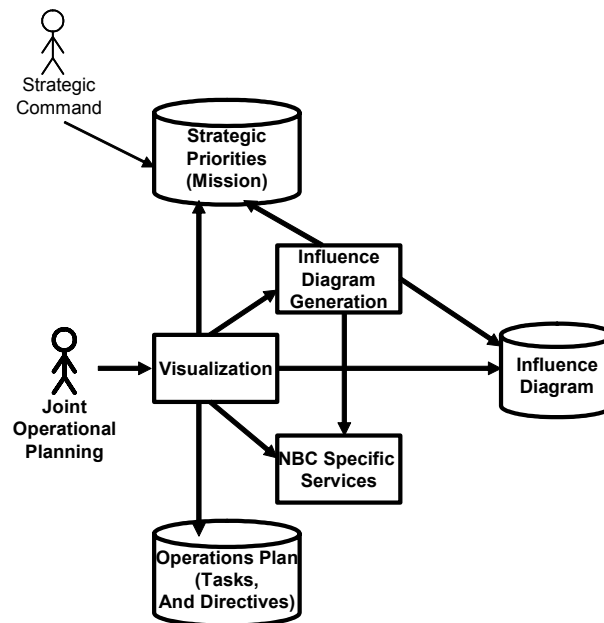


Figure 9.5. The system view of services supporting effects-based joint operational planning of NBC defense. The arc relation between two services means that one service uses the other.

In Figure 9.6, we depict such an Influence Diagram using a general open source tool for describing decision theoretic models [Genie, 2005]. According to this causal model, there is a probability that the chemical plant will be the subject for an attack, which then will cause casualties among own forces and in the civilian population. According to the example, given the current decision to establish a continuous protection of the factory, the probability for no attack on the factory is 90 %, while the probability of a small attack is 7 %, and the probability for a major attack is 2 %. In combination with the decisions to establish a warning system covering own forces but not preparing for Collective Protection, the probability of no casualties caused by a toxic release from the factory is a 93 %, the probability of more than zero casualties but less than 10 is 4 %, and the probability of more than 10 casualties is 3 %.

There may also be other NBC related threats, here omitted for simplification, which need to be considered during the planning process. Thus, the influence diagram includes a node that aggregates the expected casualties from different threats into one probability distribution. The purpose of this node is to compare the expected effects with the mission requirements. Hence, the requirements need



to be stated in terms of a scheme for classifying potential outcomes, as discussed in Section 8.3. In this case, the mission requirements state that the acceptable state, denoted 'OK', admits no casualties at all, while more than zero casualties implies an unacceptable state, denoted 'Compromised', and while more than 10 casualties is considered being a disastrous state, denoted 'Severe'.

The costs of different actions, in terms of the required number of personnel, are also aggregated in a similar manner, making it possible to compare the expected outcomes of different combinations of measures. Hence, the decision-maker may explore the space of possible decisions in order to find the optimal trade-off between cost and risks. According to the decisions made in the example in Figure 9.6, the probability for casualties may be acceptable, while the required number of personnel is too high.

Further indicated in Figure 9.5, the influence diagram should be part of a system of services that together fully support the effects-based work processes. As discussed in Section 8.3, automated methods, such as agent-based simulation, are required to fill in the conditional probability tables. In this case, we however suggest that dedicated decision support tools for NBC protection should be used (which are denoted 'NBC Specific Services' in Figure 9.5). Thus, repeated automated questions should be asked to an expert system, such as the prediction support services based on dispersion models that are presented in [FOI, 2004]. Hence, the Influence Diagram Generation Service would repeatedly be asking for the expected number of casualties given different degrees of attacks on the factory in combination with different weather conditions.

Regarding the command support issues, we have investigated two alternative solutions to present the contents of the operation plan. The first, depicted in Figure 9.7 (in Swedish), uses the DISCCO command support prototype that was introduced in Section 8.2. This solution shows that the ontology for the situation model is capable of representing the essential contents of the NBC annex of the operation plan.

During the study, we however found that the plan needs to be presented in a format that is more familiar to the decision-makers. Also, as stated in Section 8.3, the connection between the plan and

the influence diagram need to be presented in a comprehensible manner. The second solution, as depicted in Figure 9.8, is an attempt to achieve this. By the web browser oriented human-machine interface, the information pieces in the plan annex regarding NBC related mission objectives, situation, tasks and directives directly refer to the situation model but also to nodes in the underlying influence diagram. It hence provides the means to make the influence diagram graspable by aggregating its information and connecting it with the command support issues. In particular, the use of *probabars* connects the predicted outcome with the mission description according to the classification scheme, as discussed in Section 8.3. This aims at facilitating predictive situation awareness by a brief glance at the user's interface. In the case depicted in the figure, the significant red parts of the probabars indicate that there is a substantial probability of fatal consequences of current decisions.

By the browser metaphor, it is also possible to drill down to more detailed information, such as to the exact contents of the influence diagram, or to the defined tasks and directives for subordinated forces. Also, links are provided to other objects in the situation model and to any unstructured information not part of the model. Hence, also tacit and informal aspects of organization (see Section 3.2 and Section 8.1) are supported.

## Conclusions

From this study, we conclude that the DISCCO concept indeed may support decision-making during preparation of forces contributing to international operations. In particular, Influence Diagrams may be used to represent the causal mechanisms between decisions and consequences, and hence are facilitating an effects-based approach.

It has also become obvious that DISCCO emphasizes the support of general command and control issues, to complement tools dedicated to domain specific (in this case NBC) issues, such as presented in [FOI, 2004]. One example of the connection between general and domain specific services is how the Influence Diagram is utilizing results from decision support tools based on dispersion models.

Although the basic principles of DISCCO are adequate, major work remains to make the concept fully useful in real settings. Further

usability studies are required to better capture the existing work processes of the Joint Forces Command, and to improve the usability of the presentation service.



## Tasks and Directives

### Protect chemical Plant!

Protect Chemical Plant!	
No_Protection	0%
Patrolling_Regularity	0%
Continuous_Protection	100%

Required_Personell	
None	0%
Approx_5	12%
Approx_10	88%

### Establish Warning System!

Establish_Warning_System	
No_Warning_Ability	0%
Cover_Own_Forces	100%
Cover_Civilian_Popul...	0%

Required_Personell	
None	31%
Approx_10	69%
Approx_20	0%

### Prepare Collective Protection!

Prepare_Collective_Protection!	
None	100%
Minor	0%
Major	0%

Required_Personell	
None	100%
Approx_5	0%
Approx_10	0%

## Situation

Gammian Forces may attack chemical plant

Gammian Forces may attack chemical plant	
OK_No_Attack	90%
Not_OK_Small_Attack	7%
Severe_Major_Attack	2%

Casualties_Caused_by_Toxic_Industrial_Hazard	
OK_No_Casualties	93%
Not_OK_Less_than_10	4%
Severe_More_than_10	3%

## Mission

OPIL J5 shall establish directives for NBC protection

Minimize casualties caused by NBC weapons and ROTA	
OK_No_Casualties	93%
Not_OK_Less_than_10	4%
Severe_More_than_10	3%

Keep within budgetary constraints	
OK_Less_than_20_pp	62%
Not_OK_More_than_20_pp	38%
Severe_More_than_40_pp	0%

Figure 9.6. An Influence Diagram representing the causal model between actions and effects.

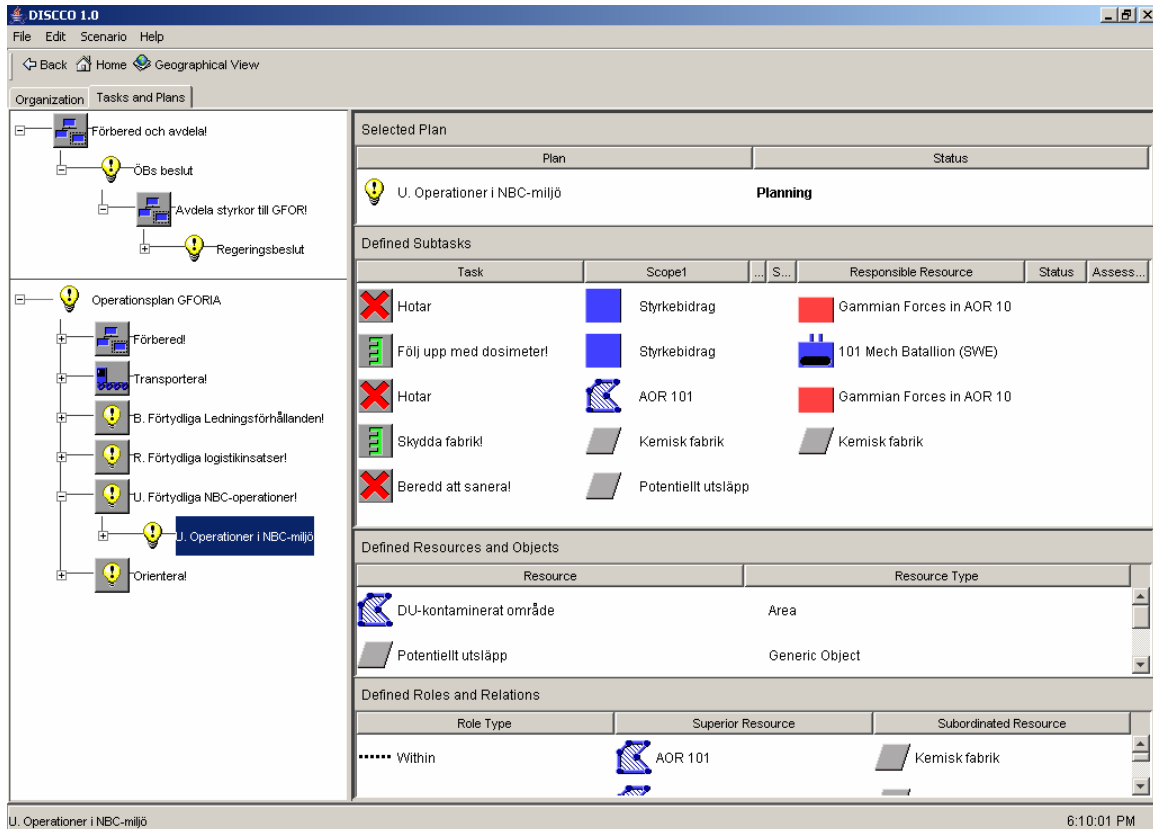


Figure 9.7. A plan view depicting the NBC annex of the operation plan (in Swedish).

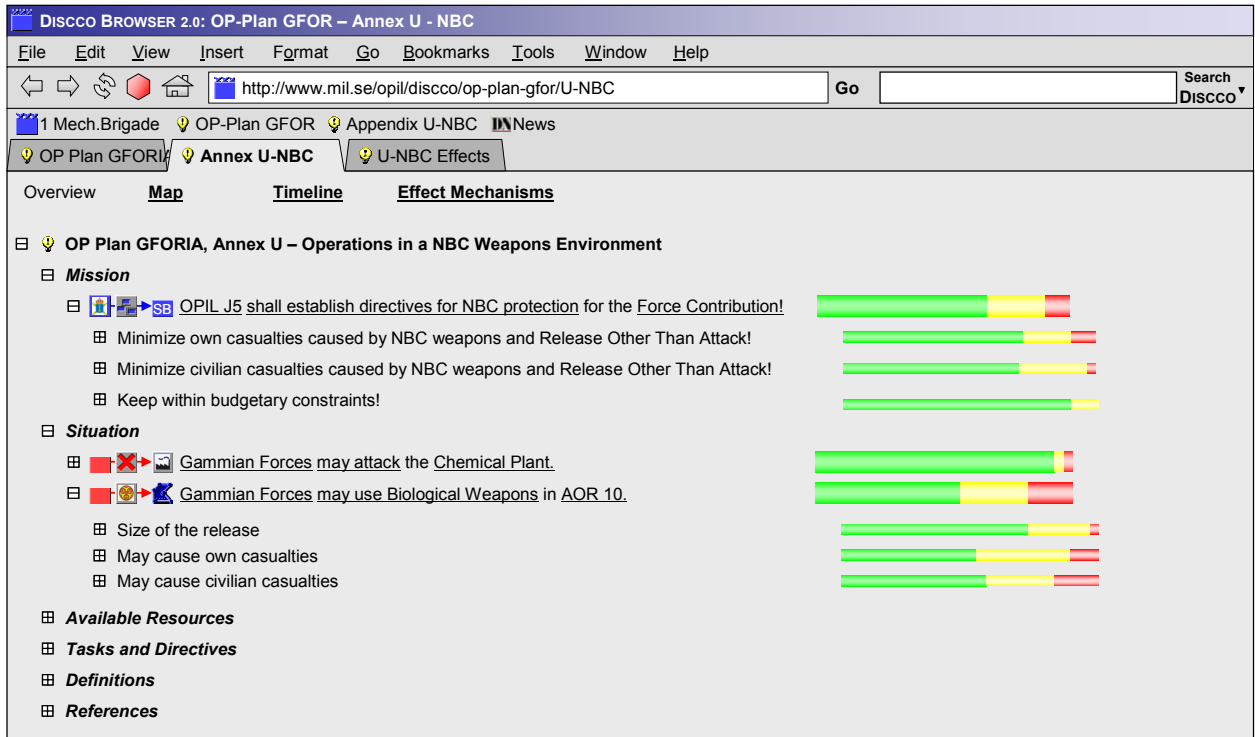


Figure 9.8. An example of a browser service visualizing the NBC annex of the operation plan together with 'probabars' representing the estimated effects of current decisions.

## 9.4 Executing Tactical Operations: Riot Control

### Background

Originally presented in [Suzić and Wallenius, 2005], this study has been carried out in collaboration between Saab, the Swedish Defense Research Agency (FOI), and the Royal Institute of Technology.

The purpose was to investigate how the use of embedded simulation could be integrated with the DISCCO concept in order to support an ongoing operation.

### The Design Process

This study has been performed without any involvement of domain experts. The main sources for understanding the case of riot control has been found in [Gaskins *et. al.*, 2004], [Grieger, 2003], and [Jager *et. al.*, 2001]. From this input, the design of a tool supporting the police or the military has been proposed from a technical point of view. Much more research, with domain experts involved, is thus required until the proposed tool will be useful for real applications.

### The Work Supported

This example deals with riot control in a middle-sized city at some stage in, e.g., the U.N. operation in Gammia. During a top summit in the city, a tactical commander belonging to the police or the military is responsible for the security.

In connection with this summit, thousands of protesters from different countries are expected to show up to exercise their rights to demonstrate for or against different issues. It is also expected that some of these protesters will be trouble-makers intending to disturb the meeting. In the case of a domestic event, the police is responsible for the security at the summit, while in the case of an international peace-keeping operation, military units may be responsible.

Nevertheless, the overall goals for the security operations are to protect the meeting and its participants, and to protect public and private property from being damaged. At the same time, the police or the military must be very cautious neither to interfere with the integrity of the protesters and their rights to free speech, nor to unnecessarily provoke potential trouble-makers to cause further harm.

The concept of EBO may facilitate this consideration of conflicting goals. EBO emphasizes actions performed to achieve effects beyond the most obvious tactical goals, i.e., in this case not just to prevent protesters from disturbing the meeting, but to maintain the rights of societal institutions to meet and to make decisions, as well as to maintain the rights of the people to protest against these decisions. Actions performed by units disposed by the commander need to be carefully synchronized to achieve these effects.

## **The Proposed Solution**

During the study, an approach was proposed to support EBO analysis in real time to facilitate decision-making for the ongoing operation. To this end, the use of Influence Diagrams is combined with embedded simulation to facilitate a continuous re-evaluation of the situation in order to optimize the actions performed by own units.

An overview of the proposed concept is presented in Figure 9.9. In the context of riot control, the tactical commander is considering alternative tactical orders to the subordinated units in order to comply with the strategic priorities from the superior commander. To facilitate this assessment, the commander gets information about the situation by means of the tactical situation picture, depicting the locations and activities of own units as well as of demonstrators. The tactical picture is based on field reports being processed by a data fusion service, as described in Chapter 6.

However, as indicated by the bold face in the figure, the main emphasis in the proposed concept is on how the tactical commander can make use of services dedicated to generate and maintain an influence diagram representing a model of the evolving situation. By this model, the uncertain effects of different actions on the tactical level can be analyzed by the commander, in order to optimize decisions on how to utilize subordinated units.



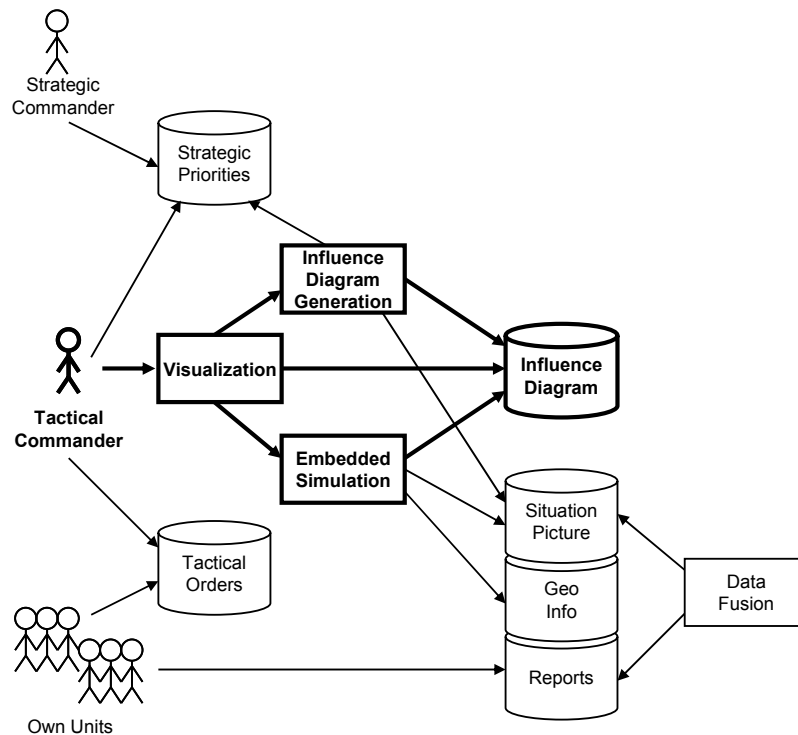


Figure 9.9. The system view of services supporting effects-based riot control. The arc relation between two services means that one service uses the other. Bold face indicates the emphasis in this study.

A subset of such a model of the riot situation is depicted in Figure 9.10. In the first column, the *action nodes* represent decision alternatives for subordinated forces and clusters of protesters. In the second column, *partial assessment nodes* represent the joint probability density functions of local effects, e.g., damage to buildings or casualties among own units or among protesters, caused by the decisions made in the first column. In the third column, the *end effect nodes* aggregate the local effects to correspond to the goals for the operation in different attributes. Finally, one further aggregation of the effects is made. Hence, the overall performance of the operation is represented by the *aggregated consequences* node on the right in the figure.

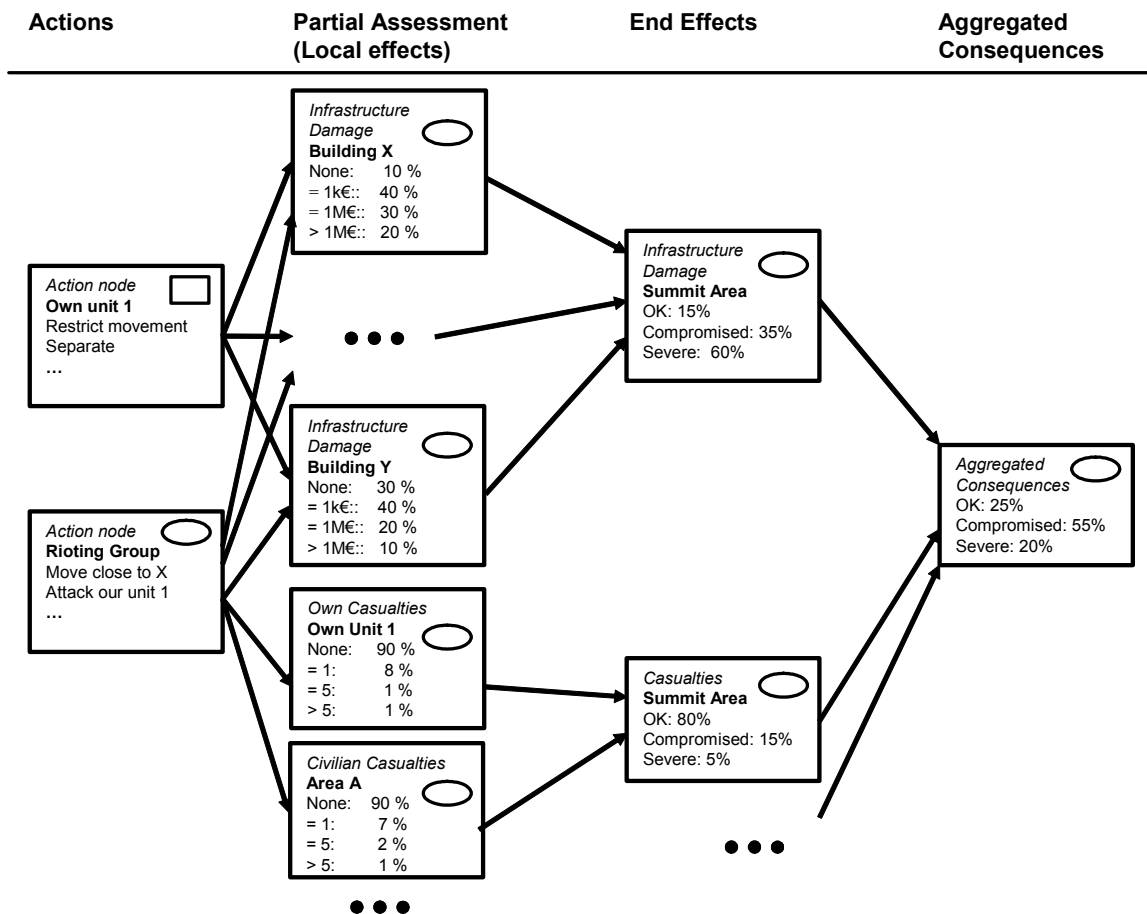


Figure 9.10. An influence diagram representing the causal relationships between actions and effects [Suzić and Wallenius, 2005].

The conditional probability tables in the partial assessment nodes are calculated by executing a set of embedded simulations hosting performance models of the units involved. The simulations performed at a certain decision point in time are repeated to get a successively better estimation of the expected local effects. This continues as long as the time for making the decision allows, and as long as it is considered meaningful, depending on whether additional simulations are expected to improve the estimation or not. See [Suzić and Wallenius, 2005] for a further discussion on the implementation of this *agent-based embedded Monte Carlo simulation*.

Figure 9.11 suggests how the influence diagram resulting from the simulations can be used by a tactical commander. On the left in the figure, the situation picture is depicted with positions of, e.g., important objects, protesters and own units. On the right, the assessed outcome is presented, given the current tasks assigned to the own units. For each of the strategic goals, the probabilities of different outcomes are presented using 'probabars', in line with the example with NBC defense presented in the previous section. For example, the probabar labeled 'Protect Meeting & VIP' indicates that the probability of that the top meeting will be performed without disturbances is around 80 %, while the probability of that the meeting will have to be stopped for some time is around 12 %, and finally, that the probability of that, e.g., the meeting must be cancelled or that some of the delegates will be injured is also around 8 %. Also, the aggregated assessment is presented, indicating that the probability for the total operation to fulfill the goals is around 40 %, and the probability for a disastrous outcome is around 10 %. These are seriously bad odds, and thus some new decisions need to be made quickly by the commander.

By right-clicking on any of the own units, as depicted in Figure 9.12, new assignments can be given to them. At a first step, this can be made tentatively to test out new strategies for dealing with the threatening situation. Changing the assignments will give new information to be processed by the influence diagram and the Monte Carlo simulations. The tactical commander may thus use the underlying influence diagram to examine causalities between actions and effects and thus improve his or her situation awareness. Possibly a better strategy can be found that reduces the probability for severe consequences, which then will be indicated by the probabars. If so, the tentative assignments can be changed to definite assignments and thus ordering the subordinated units to perform according to the new strategy.

## Conclusions

In this study, a concept for real-time effects analysis has been introduced. By not involving any reference persons, the concept has been examined mainly from a technical and a conceptual point of view. Hence, the user interface presented in Figure 9.11 and Figure

9.12 is designed merely to give an indication of how it may appear from a commander's point of view. To ensure the usability of the final design, further iterative user studies will be essential for future development. Also, major challenges remain in the implementation of the simulations and in the design of the technical architecture. Further research aims at getting a deeper understanding of the advantages and limitations of the concept. The interesting issues include how to deal with complexity in uncertain situations and find out more about the challenges imposed by the use of embedded simulation.

Nevertheless, by the agent-based approach to simulation, the problem of analyzing effects in a complex system has been reduced to modeling the performance of smaller subsystems, which is a much easier task. By the achieved ability to predict the effects and risks of potential actions in the context of superior goals, the situation awareness of the commander should be greatly facilitated. As the risk perspective is a fundamental part of the analysis, the ability to test the robustness of tentative plans should contribute to this awareness.

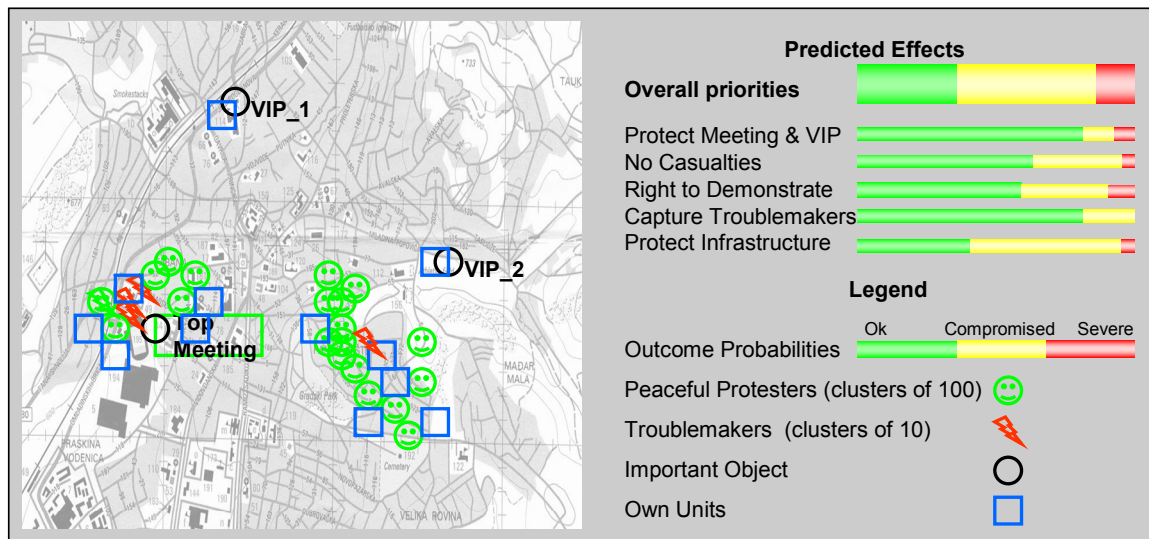


Figure 9.11. An example of a user interface service presenting the assessed consequences of current actions, along with the situation picture.

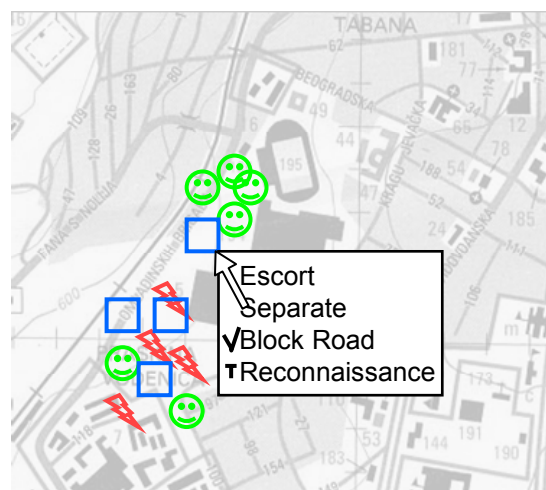


Figure 9.12. Own units can be assigned tasks, either tentatively (to test consequences) or definitely (to submit new orders).



# **Chapter 10**

## **Conclusions**

The present work aims at describing a framework for the development of tools to support Effects-Based Management of Operations, in line with the definition given in Section 2.3. Concluding this presentation, we will start with recapitulating the basis for this approach from different aspects on Command and Control, Effects-Based Management of Operations, organization, and decision-making. After that, we will summarize on the main properties of the framework, and discuss the generality of it. Finally we will present a roadmap for future development of the support tools.

### **10.1 The Properties of the Supported Work**

In Chapter 2, we gave a definition, stating that C2 is the work of making optimal use of available resources to fulfill a task. To this end, C2 is the act of making decisions on the organization of the available resources, and the assignment of tasks to these resources. This view on C2 is recursive, since the assigned tasks give rise to C2 on lower decision-levels, and so forth. We also found that, in this context, the mainly military concept of C2 is very similar to the term “management” inherited from the business sector. To further emphasize the effects that are to be achieved in different domains, the concept of Effects-Based Operations (EBO) is merged with C2 into our proposed definition of Effects-Based Management of Operations.

To further investigate the properties of C2 and management, Chapter 3 discussed non-traditional aspects of organization, finding that, in order to be prepared for future ways of working in the military, the tools need to support multi-dimensional and dynamic organization

structures. Also, the tacit view on organization needs to be emphasized when designing the tools.

From this, Chapter 4 looked into prescriptive and descriptive aspects of decision-making. We argued that predicting the consequences of a decision is an act of induction. As this kind of reasoning always is uncertain, the Bayesian view on uncertain knowledge, represented by subjective probabilities, provide the means to represent the decision-making in a rational manner. The human, however, is considered having significant problems with interpreting this way of representing uncertain information, which is something that needs to be addressed in the design process. To further deal with the uncertain results of induction, the decision-making is considered being dynamic. To this end, feedback from the results of the decisions gives new information as time passes. Thus, during the execution, the decisions may be reconsidered and adjusted according to this new information. Another aspect that needs to be considered is that the goals of the tasks in C2 are mainly multi-dimensional. Hence, the theories on multi-attribute decision-making bring further complexity to the decision-making in the C2 case. Finally in this chapter, we discussed the differences between different decision-processes that the military have been using. Hence, the designed tools need to support both traditional prescriptive models and novel models that are based on results from the area of Naturalistic Decision-Making.

## **10.2 Support Tools**

In Chapter 5, we presented a classification of different tools that support decision-making in the context of Effects-Based Management of Operations. The suggested structure, depicted in Figure 5.3, is based on the definition of different levels of Situation Awareness (SA) as proposed by [Endsley, 1995]. According to this definition, SA is human knowledge represented by mental states. Thus, it is different from information on the situation, represented in a database or by another technical artifact. Data Fusion, on the other hand, is the process to achieve such information in the databases. Data Fusion techniques can be divided into levels comparable to the levels of SA. Hence, the JDL Model [Steinberg and Bowman, 2001] shows great



similarities with Endsley's definition of SA, and we can thus formulate the classification based on these different levels.

The commanders at different positions in the military organization can be seen as a system of decision-makers each having their own SA, based on observations made in the real world and on previously acquired knowledge. We identified that there are both objective and subjective aspects of SA, both implying that the SA should be shared among the decision-makers. As for the objective part, the decision-makers will make better decisions if they can utilize each other's knowledge of the real world. As for the subjective part, the interaction between the decision-makers will gain if they can interpret the situation in a consistent manner, hence facilitating a better synchronization of the decisions. As the Common Situation Model and the Command Support, described in Section 8.1 and in Section 8.2, can be used to formulate the knowledge on friendly, as well as hostile, forces, they support the externalization of SA. Hence, they provide the main instrument for the decision-makers to share and agree upon the subjective interpretation of the situation.

From the perspective of the generic decision-making process in Figure 7.1, the Common Situation Model and the Command Support tools provide the means to manually formulate and assess different potential solutions to the task. These solutions are represented by plans that define organization, tasks, and assignments on subordinated decision-levels. A decision is formally made on these matters by approving such a plan. The decision is hence immediately made available to subordinated decision-levels, providing the order to act according to it. It is also made available to other decision-makers that are not formally affected by the decision, such as peer commanders, who may use this information as a basis for their own decision-making.

Complementing the manual Command Support, different kinds of 'clever' technology is applied to amplify the human cognitive ability. To this end, Multi-Sensor Data Fusion uses data from different kinds of sensors to support SA on the lowest level, consisting of hostile as well as own forces. In Chapter 6, we provided an example of how such tools may be constituted by describing the WASP concept. This approach aims at correlating and distributing target tracks from different sources in a robust and flexible manner. To support the

higher levels of SA regarding hostile forces, Information Fusion is applied, including the support for estimating their organization, and the support for estimating the enemy's plan. This is, however, an issue that we did not develop any further in the present work.

In contrast, Decision Support, as presented in Section 8.3, encompasses clever tools to evolve and assess own decisions following the generic decision-making process. Hence, these tools include means to represent the goals, to evolve solutions, to predict their consequences, and to compare these with the goals. To this end, the techniques of agent-based simulation, and Influence Diagrams, provide the basis for the decision support tools, by allowing for breaking down the assessment into tractable pieces and by involving the notion of uncertainty as an integrated part of the analysis.

## **10.3 Usability and Applicability**

In Chapter 8, the concept of DISCCO was introduced, implementing the proposed framework including the Common Situation Model, Command Support, and Decision Support. The generic features of DISCCO are guaranteed mainly by the constitution of the UML model that represents the ontology for the Common Situation Model. By the object-oriented approach it is possible to describe general classes and their relations, and, at the same time, allow for specializations for specific cases.

In Chapter 9, the use of DISCCO was investigated in three different applications: Planning for establishing surveillance of an operation area, planning for NBC defense, and executing a riot control mission. The involvement of reference persons in the process, at least to a minor extent, has contributed to the usability of the developed concept. However, much more studies are required to fully understand the needs of different users and how to design purposeful tools based on the concept.

Nevertheless, as suggested in Figure 9.1, we argue that the studies presented in Chapter 9 indicate that DISCCO is applicable in many of the different classes of Effects-Based Management of Operations. The generic qualities of DISCCO can thus be summarized by the

following list of different aspects of management that can be supported by the tools:

- *Different command levels, services and activities.* The differences between different instances of Effects-Based Management of Operations may lie in the time span, the level of details, and the kind of details, but from our point of view there are no conceptual differences in how to make and represent decisions.
- *Static and dynamic organizations.* From the technical point of view, a static organization is a special case of dynamic organization. By emphasizing on dynamic and multiple organizations, as these tools do, the static case can always be represented.
- *Formal and informal organizations.* There are currently no restrictions on who can access information and who can make decisions according to the model, thus supporting both kinds of organization. Further development of the model, as described in the next section, includes interaction with authority servers to represent such restrictions, providing the means for security management.
- *Explicit and tacit organizations.* There is no conceptual difference between explicit and tacit C2. Entities such as tasks and organizations are meaningful in both domains. In the explicit case, these entities exist in a structured manner on paper or in the computer. In the tacit case, they serve as models of what is going on within the minds of individuals. Our aim is to design technical solutions that can help the individuals to externalize more of the tacit domain, in order to a) facilitate communication of these entities between individuals, b) relieve some of the individual's cognitive capacity in that they get an overview of what they are thinking, and c) provide the basis for future development of clever tools performing parts of the decision-making. However, to facilitate the substantial part of the tacit domain that cannot be captured in the structured model efficiently enough, supplementary and non-structured communication channels such as e-mail, video and telephone must be provided.

- *Different planning models and decision-making theories.* The generic decision-making process is independent of the different prescriptive and descriptive planning processes that were discussed in Section 4.3.
- *Different phases of the mission.* According to the dynamic view of decision-making, the feasibility of the potential solutions has to be reconsidered and new solutions have to be evolved over and over again, before, during, and after the mission. Thus, the same means for interaction may be used during all of these phases.
- *A various degree of automation.* The suggested framework is designed from the perspective that the basis for C2 is manual work, but that tools enhancing the human cognitive capability can support this manual work. Such automated tools can successively be developed and incorporated among the manual tools.

The major concern, however, is that particular domain knowledge has been left outside the model. Commanders, according to the model, manage resources by inventing and assessing solutions to the problem at hand. Their decisions depend on professional skills, experiences, intuition, and perhaps also on sophisticated simulation models, all greatly depending on domain. Still, the way to perform this work looks similar in any organization and for any type of activity.

## 10.4 Further Development

The roadmap for the DISCCO system, depicted in Figure 10.1, indicates the different issues that need to be solved to make the presented tools operational. This roadmap suggests a successive introduction of functionality in four stages. The first stage focuses on the manual description of situation and plans, using the different views in the Command Support tools. The second stage emphasizes the simulation-based evaluation of plans during the planning and execution of the tasks. The third stage involves support to automatically evolve plans. Finally, the fourth stage includes the concepts of uncertainty, risks, and game theory. Also indicated in the

roadmap, is the integration of services that are not part of the actual DISCCO system. Of these, the integration of Multi-Sensor Data Fusion and Information Fusion has already been discussed. Further services to integrate include Geographical Information Systems (GIS), and security systems managing the authorities to access information and to utilize resources within the organization.

Planning and Situation	Evaluation and Monitoring	Enhanced Planning	Uncertainty
<ul style="list-style-type: none"> <li>• Planning in all views (time, geographical, and trees)</li> <li>• Dynamic situation</li> <li>• Multiple users</li> <li>• Basic embedded simulation</li> <li>• Provided as network-based services</li> <li>• Relations to multi-sensor data fusion services</li> <li>• Methodology studies</li> </ul>	<ul style="list-style-type: none"> <li>• Simulation-based plan evaluation</li> <li>• Monitoring of plan execution and deviation from normal situation</li> <li>• Example of control of autonomous systems</li> <li>• Relations to GIS services</li> <li>• Methodology studies</li> </ul>	<ul style="list-style-type: none"> <li>• Support for plan generation</li> <li>• Regard authority, rules, and regulations</li> <li>• Relations to authority services</li> <li>• Methodology Studies</li> </ul>	<ul style="list-style-type: none"> <li>• Uncertainty-based situation model</li> <li>• Plan evaluation based on game theory and interdependent actors</li> <li>• Assessment of threat, risk, and info utility</li> <li>• Relations to information fusion services</li> <li>• Methodology studies</li> </ul>

Figure 10.1. A roadmap for further development of the DISCCO system.

The roadmap indicates that DISCCO has a rather broad scope and that there are several critical issues for this development. These include the ontology for the Common Situation Model, which needs to be worked out in a number of details according to the discussion in Section 7.5. Especially the issue on how to represent uncertainty in the model will need much attention. Among the decision-support tools, the integration of agent-based simulation and Influence Diagrams will require a substantial effort of research. So far, there has not been much work on the actual design of the user-interfaces, although the quality of these would clearly be crucial for the applicability of the tools. Some usability and methodology issues have been touched upon during the studies in Chapter 9, however much further emphasis on these is required, as indicated in the roadmap.

To better show the advantages of the tools, the work according to the roadmap needs to start with the development for a more restricted class of users than has been the case so far. The typical case of Effects-Based Management of Operations, according to our definition, depicts work somewhere on the middle levels of a large organization hierarchy, dealing with decisions for abstract resources rather than physical resources, i.e., there are subordinated decision-levels to carry out tasks. Hence, we suggest that further efforts should be addressed to support ground-based military forces, in which many organization levels are involved in the planning and execution of missions. Suitable levels to start with are the division and brigade levels in the army. These decision-levels deal with abstract units, the planning cycles span over a suitable amount of time, and the C2 work is performed in an environment that should admit the usage of ordinary personal computers and the connection to broadband networks. Together, these parameters seem appropriate for the first attempts in developing and using the tools here suggested.

The development according to the roadmap will result in tools that will be useful already after the first stage, by increasing the efficiency of a restricted class of users in their work to plan for missions. The framework provided will admit a continuously increasing functionality. From the experiences reached in this development, the scope can be successively expanded to support a larger class of users. Hence, further decision-levels, further military services than the army, and also civilian services such as rescue services and police, may be supported.

The work for these different users will be significantly enhanced in terms of better situation awareness and faster decision-making. Furthermore, taking full advantage of the network, the interaction between the users will be greatly facilitated by the support to share the mental awareness of the situation, and the awareness of the decisions made on how to deal with it. Consequently, generic support tools, such as provided by DISCCO, will play a significant role in using available civilian and military capabilities to achieve desired effects. Providing support for monitoring, planning, analyzing, and executing Effects-Based Operations, they have a great potential to contribute when dealing with natural, as well as man-made, post cold war threats to the society.

# Bibliography

[Alberts *et al.*, 1999] David S. Alberts, John J. Gartska, Frederick P. Stein. *Network Centric Warfare: Developing and Leveraging Information Superiority*. U.S. DoD, 1999.

[Anthony, 1999] Robert W. Anthony. Relating Large and Small in C2 and Operations. In *1999 Command and Control Research and Technology Symposium*, United States Naval War College, Newport, RI, June 29-July 1, 1999.

[Arnborg, et. al., 2000] Stefan Arnborg, Henrik Artman, Joel Brynielsson, and Klas Wallenius. Information Awareness in Command and Control: Precision, Quality, Utility. In *Proceedings Third International Conference on Information Fusion (FUSION 2000)*, pp. ThB1/25–32, Paris, July 2000.

[Arnborg and Sjödin, 2000] Stefan Arnborg and Gunnar Sjödin. Bayes rules in finite models. In *Proc. European Conference on Artificial Intelligence*, pp 571—575, Berlin, 2000.

[Artman, 1999] Henrik Artman. *Fördelade kunskapsprocesser i ledningscentraler vid nödsituationer*. Avhandling nr. 186. Tema Kommunikation, Linköpings universitet. Motala: Kanaltryckeriet. Sverige, 1999. In Swedish.

[Beer, 1959] Stafford Beer. *Cybernetics and Management*. The English Universities Press LTD, London, 1959.

[Berger 1985] James O. Berger. *Statistical Decision Theory and Bayesian Analysis*. Springer-Verlag, New York, second edition, 1985.

[Bergman and Wallenius, 2001] Niclas Bergman and Klas Wallenius. Providing the Common View of the Situation – the WASP Approach. In *Information Management Challenges in Achieving Coalition Interoperability*, Quebec City, Canada, May 29-30, 2001.

[Blackman and Popoli, 1999] Samuel S. Blackman and Robert Popoli. *Design and Analysis of Modern Tracking Systems*. Artech House, 1999.

[Blaker, 1996] Jim Blaker. The Former Vice Chairman of the Joint Chiefs Laid the Groundwork for a Revolution. In *Armed Forces J. Int.*, 20-22, July, 1996.

[Borchert and Jones, 1999] Alistair Borchert, Carl R. Jones. Organizational Fitness of a Proposed Network Centric Organization. In *1999 Command and Control Research and Technology Symposium*, United States Naval War College, Newport, RI, June 29-July 1, 1999.

[Boury-Brisset, 2003] Anne-Claire Boury-Brisset. Ontology-based Approach for Information Fusion. In *Proceedings of the 6th International Conference on Information Fusion*, Cairns, Queensland, Australia, July 8-11, 2003.

[Brehmer, 1992] Berndt Brehmer. Dynamic decision making: Human Control of complex systems. In *Acta Psychologica* 81, pp. 211-241. North Holland, 1992.

[Brehmer, 2003] Berndt Brehmer. Tid i det nya kriget: Den dynamiska beslutscykeln som ett alternativ till OODA-cykeln. In Gunnar Artéus, Berndt Brehmer, editors, *Essäer om det nya kriget*. Swedish National Defence College, Stockholm, 2003. In Swedish.

[Brynielsson, 2002] Joel Brynielsson. A Decision-Theoretic Framework Using Rational Agency. In *Proceedings of the 11th Conference on Computer Generated Forces and Behavior Representation*, 02-CGF-047, pages 459-463, Orlando, FL, May, 2002.

[Brynielsson, 2004] Joel Brynielsson. Game-Theoretic Reasoning in Command and Control. In *Proceedings of the 15th Mini-EURO Conference: Managing Uncertainty in Decision Support Models (MUDSM 2004)*, Coimbra, Portugal, September 2004.

[Brynielsson et. al., 2005] Joel Brynielsson, Mattias Engblom, Robert Franzén, Jonas Nordh, and Lennart Voigt. Enhanced Situation Awareness using Random Particles. In *Proceedings of the Tenth International Command and Control Research and Technology Symposium (ICCRTS)*, McLean, Virginia, June 2005.



[Brynielsson and Arnborg, 2004] Joel Brynielsson and Stefan Arnborg. Bayesian Games for Threat Prediction and Situation Analysis. In Proc. Seventh International Conference on Information Fusion (FUSION 2004), Stockholm, Sweden, June 28 to July 1, 2004. In press.

[Brynielsson and Arnborg, 2005] Joel Brynielsson and Stefan Arnborg. Refinements of the Command and Control Game Component. In *Proceedings of the Eighth International Conference on Information Fusion (FUSION 2005)*, Philadelphia, Pennsylvania, July 2005.

[Brynielsson and Arnborg, 2006] Joel Brynielsson and Stefan Arnborg. Bayesian Games for Threat Prediction. To appear in *Journal of Advances in Information Fusion*. Volume 1, Number 1. April 2006.

[Brynielsson and Wallenius, 2001] Joel Brynielsson and Klas Wallenius. Game Environment for Command and Control Operations (GECCO). In *Proceedings of the First International Workshop on Cognitive Research With Microworlds*, pages 85–95, Granada, Spain, November 2001.

[Brynielsson and Wallenius, 2003] Joel Brynielsson and Klas Wallenius. *A Toolbox for Multi-Attribute Decision-Making*. Technical Report TRITA-NA-0307, Department of Numerical Analysis and Computer Science, Royal Institute of Technology, 2003.

[Chandrasekaran *et al.*, 1999] B. Chandrasekaran, John. R. Josephson and V. Richard. Benjamins. What Are Ontologies, and Why Do We Need Them? In *IEEE Intelligent Systems*, Vol.14, No. 1, Special Issue on Ontologies, January / February 1999, pp. 20-26.

[Chin *et al.*, 1999] Moira Chin, Penelope Sanderson, and Marcus Watson. Cognitive Work Analysis of the Command and Control Work Domain. In *1999 Command and Control Research and Technology Symposium*, United States Naval War College, Newport, RI, June 29-July 1, 1999.

[Coakley, 1991] Thomas P. Coakley. *Command and Control for War and Peace*. National Defense University Press, Washington, DC, 1991.

[Cohen, 1998] Michael D. Cohen. Foreword in M. Prietula, K. Carley, and L. Gasser, editors, *Simulating Organizations: Computational Models of Institutions and Groups*. AAAI Press/MIT Press, 1996.

[Cox, 1946] Richard T. Cox. Probability, frequency, and reasonable expectation. *Am. Jour. Phys.*, 14:1-13, 1946.

[Curts and Campbell, 2001] Raymond J. Curts, Douglas E. Campbell. Avoiding Information Overload Through the Understanding of OODA Loops. A Cognitive Hierarchy and Object-Oriented Analysis and Design. *6th International Command and Control Research and Technology Symposium*, U.S. Naval Academy, Annapolis, Maryland, 19-21 June 2001.

[Dahlbom, 2000] Bo Dahlbom. Nomadic Networking. In K.Braa, C.Sørensen, and B.Dahlbom, editors, *Planet Internet*, Studentlitteratur, Lund, 2000.

[de Finetti, 1974] Bruno de Finetti. *Theory of Probability*. London:Wiley, 1974.

[Dourish and Bellotti, 1992] Paul Dourish and Victoria Bellotti. Awareness and coordination in Shared Workspaces. In J. Turner, and R. Kraut, editors, *Proceedings of ACM CSCW 92*, 1992.

[Duczynski, 2004] Guy Duczynski. Effects-Based Operations: A Guide for Practitioners. In *Proceedings of 2004 Command and Control Research and Technology Symposium*, San Diego, California, June 15-17

[Edlund, 2004] Johan Edlund. An Agent Based Approach to Situation Assessment. In *Proceedings of Second International Conference on Military Technology*. Stockholm, Sweden, October 25-26, 2005.

[Ellsberg, 1961] Daniel Ellsberg. Risk, ambiguity and the Savage axioms. *Quart. J. Econ.*, 75:643–669, 1961.

[Elwell, 1996] Frank Elwell. *The Sociology of Max Weber*, 1996, Retrieved July 23, 2003. <http://www.faculty.rsu.edu/~felwell/Theorists/Weber/Whome.htm>

[Endsley, 1995] Mica R. Endsley. Toward a theory of situation awareness in dynamic systems. In *Human Factors*, 37(1), 32-64, 1995.

[FOI, 2004] *Demonstrator NBC-ledningsystem – Etapp 1. Lägesrapport 3, utgåva 1.0*. Swedish Defence Research Establishment (FOI), October 2004. In Swedish.

[Fowler, 1997] Martin Fowler. *Analysis Patterns*. Addison-Wesley, 1997.

[Fowler, 1999] Martin Fowler. UML Distilled: A Brief Guide to the Standard Object Modeling Language. Second Edition. Addison-Wesley, 1999.

[Gagnon and Stevens, 1999] Colleen M. Gagnon and William K. Stevens. Use of Modeling and Simulation (M&S) in Support of Joint Command and Control Experimentation: Naval Simulation System (NSS) Support to Fleet Battle Experiments. In *Proceedings 1999 Command and Control Research and Technology Symposium*, June 1999.

[Gaskins *et. al.*, 2004] Ryland C. Gaskins III, Carlotta M. Boone, Thomas M. Verna, and Mikel D. Petty. Cognitive and behavioral psychological research for crowd modeling. In *NATO Modeling and Simulation Group Conference*, Koblenz, Germany, October 2004.

[Genie, 2005] The GeNIe and SMILE Webb site, retrieved in July 2005, <http://www.sis.pitt.edu/~genie/>

[Giffin, 2002] Ralph E. Giffin, Superstitious Rituals. Naïve Inductionism in Command and Control Doctrine: Its Causes, Consequences and Cures. In *7th International Command and Control Research and Technology Symposium*, Loews Le Concorde Hotel, Quebec City, QC, Canada, 2002.

[Gmytrasiewicz and Durfee, 2000] Piotr J. Gmytrasiewicz and Edmund H. Durfee. Rational co-ordination in multi-agent environments. In *Autonomous Agents and Multi-Agent Systems*, 3(4):319-350, December 2000.

[Goodman *et. al.*, 1997] I. R. Goodman, Ronald P. S. Mahler, and Hung T. Nguyen. *Mathematics of Data Fusion*. Kluwer Academic Publishers, 1997.

[Grieger, 2003] Dion Grieger. *An Overview of Crowd Control Theory and Considerations for the Employment of Non-Lethal Weapons*. DSTO System Sciences, Technical report DSTO-GD-0373, Laboratory, Edinburgh, AU, 2003.

[Huang *et. al.*, 2003] Qi Huang, Jenny Hållmats, Klas Wallenius, and Joel Brynielsson. Simulation-Based Decision Support for Command and Control in Joint Operations. In *European Simulation Interoperability Workshop 2003*, 03E-SIW-091, pages 591-599, Stockholm, Sweden, June 16-19, 2003.

[Horne, 1999] Gary E. Horne. Maneuver Warfare Distillations: Essence not Verisimilitude. In P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, editors, *Proceedings of the 1999 Winter Simulation Conference*, 1999.

[Hutchinson, 1995] D.S. Hutchinson. Ethics. In Barnes, editor, *The Cambridge Companion to Aristotle*. Cambridge University Press, Cambridge, New York, 1995.

[Ilachinski, 1997] Andrew Ilachinski. *Irreducible Semi-Autonomous Adaptive Combat (ISAAC): An Artificial-Life Approach to Land Warfare*. CRM 97-61.10. Center for Naval Analyses, VA, August 1997.

[Ilachinski, 1998] Andrew Ilachinski. Irreducible Semi-Autonomous Adaptive Combat (ISAAC). In F. G. Hoffman and G. Horne, editors, *Maneuver Warfare Science 1998*, pages 73–83. Marine Corps Combat Development Command, Quantico, VA, 1998.

[Jager *et. al.*, 2001] Wander Jager, Roel Popping and Hans van de Sande. Clustering and fighting in two-party crowds: Simulating the Approach-avoidance Conflict, In *Journal of Artificial Societies and Social Simulation* vol. 4, no. 3, 2001.

[Jaynes, 2003] Edwin T. Jaynes. *Probability Theory: The Logic of Science*. Cambridge University Press, 2003.

[Jensen, 2001] Finn V. Jensen. *Bayesian Networks and Decision Graphs*. Springer 2001.

[Johansson, 2003] Ronnie Johansson. *Information Acquisition in Data Fusion Systems*. Licentiate thesis, Nada, Royal Institute of Technology, Stockholm, Sweden, 2003.

[Johansson and Suzić, 2005] Ronnie Johansson and Robert Suzić. Particle filter-based information acquisition for robust plan recognition. In *Proceedings of the Eighth International Conference on Information Fusion (FUSION 2005)*, Philadelphia, Pennsylvania, July 2005.

[Jönsson *et. al.*, 1998] Lena Jönsson, Göran Neider, Johan Schubert, and Per Svensson. *Informationsfusion i den taktiska underrättelseprocessen*. FOA-R-98-00902-505—SE. Försvarets forskningsanstalt, Avdelningen för Ledningssystemteknik. December, 1998. In Swedish.

[Klein, 1989] Gary Klein. Strategies of Decision Making. In *Military Review*, pp 56-64, May, 1989.

[Kleindorfer *et. al.*, 1993] Paul R. Kleindorfer, Howard C. Kunreuther, and Paul J. H. Schoemaker. *Decision Sciences: An Integrative Perspective*. The Press Syndicate of the University of Cambridge, 1993.

[Kuylenstierna *et. al.*, 2003] Jan Kuylenstierna, Joacim Rydmark, Hans Sandström. *Betydelsen av överlägsen sensorräckvidd vid olika nivåer på osäkerhet om läget i stridsrummet*. Forskningsrapport, "Informationsbehov i framtida krig". Bilaga 2 till FHS 21 105:60998. Swedish National Defence College, Stockholm, 2003. In Swedish.

[Lichtenberg, 2000] Steen Lichtenberg. Proactive management of uncertainty using the successive principle : a practical way to manage opportunities and risks. Polyteknisk press, Copenhagen, 2000.

[Lindberg, 2003] Erik Lindberg. *Bayesiansk hypotesprövning för utvärdering av fiendens handlingsalternativ*. Master's thesis, Nada, Royal Institute of Technology, Stockholm, Sweden, 2003.

[Löwgren, 1993] Jonas Löwgren. *Human-computer interaction: What every system developer should know*. Studentlitteratur, Lund, 1993.

[Löwgren and Stolterman, 1998] Jonas Löwgren and Erik Stolterman. *Design av informationsteknik*. Studentlitteratur, Lund, 1998. In Swedish.

[Mahler, 2001] Ronald Mahler. Random Set Theory for Target Tracking and Identification. In D. L. Hall, J. Llinas, editors, *Handbook of Multisensor Data Fusion*, CRCPress, New York, 2001.

[Matheus, *et. al.*, 2003] Christopher. J. Matheus, Mieczyslaw M. Kokar, and Kenneth Baclawski. A Core Ontology for Situation Awareness. In *Proceedings of the 6th International Conference on Information Fusion*, Cairns, Queensland, Australia, July 8-11, 2003.

[McKearney, 2000] T. J. McKearney. Collaborative Planning for Military Operations: Emerging Technologies and Changing Command Organizations. In *2000 Command and Control Research and Technology Symposium*, Naval Postgraduate School, Monterey, CA, June 26-28, 2000.

[Merriam-Webster, 1998] *The Merriam-Webster Dictionary*. Merriam-Webster, Incorporated, Publishers, Springfield, Massachusetts, 1998.

[Montgomery, 1992] Henry Montgomery. Decision-Making. In L.-G. Lundh, H. Montgomery, and Y. Wærn, editors, *Cognitive Psychology*, chapter 6, pages 171–188. Studentlitteratur, 1992. In Swedish.

[Myerson, 1991] Roger B. Myerson. *Game Theory: Analysis of Conflict*. Harvard University Press, 1991.

[NATO, 1998] *Strategic Commanders Guidelines for Operational Planning (GOP)*. IMSTAM (OPS) – 243 – 98 SHAPE. NATO HQ, Military Committee, Brussels, 1998.

[NATO, 2003] Allied Joint Doctrine for NBC Defence, AJP-3.8, NATO, July 2003.

[Neumann and Morgenstern, 1953] John von Neumann and Oskar Morgenstern. *Theory of Games and Economic Behavior*. Third edition. Princeton University Press, 1953.

[Nilsson, 2000] Per Nilsson. Swedish defence undergoing change: From brute force to brain power. In *The Swedish Journal of Military Technology*, 3/2000.

[Nilsson, 2003] Per Nilsson. Opportunities and risks in a Network Based Defence. In *The Swedish Journal of Military Technology*, 3/2003.

[Osborne and Rubinstein, 1994] Martin J. Osborne and Ariel Rubinstein. *A Course in Game Theory*. MIT Press, Cambridge, MA, 1994.

[Raiffa, 1968] Howard Raiffa. *Decision Analysis: Introductory Lectures on Choices Under Uncertainty*. Addison–Wesley, Reading, MA, 1968.

[Rasmussen, 1993] Jens Rasmussen. Skills, rules, knowledge; signals, signs and symbols and other distinctions in human performance models. In *IEEE transactions: Systems, Man & Cybernetics*, SMC-13, 257–267, 1993.

[Rejnus *et. al.*, 2004] Lars Rejnus, Johan Jenvald, and Magnus Morin. A Swedish Approach to Network Based CBRN Decision Support in

Future Missions. In *proceedings of 2004 Command and Control Research and Technology Symposium*, San Diego, California, June 15-17.

[Richards, 2001] Chester W. Richards. *A Swift Elusive Sword. What if Sun Tzu and John Boyd did a National Defense Review?* Center of Defense Information, Washington, DC, May 2001.

[Roman, 1996] Gregory A. Roman. The Command or Control Dilemma: When Technology and Organizational Orientation Collide. U.S. Air Force Project 2025, 1996.

[Runqvist, 2004] Agnes Runqvist. Threat Evaluation. *An Application for Air Surveillance Systems*. Information Technology Engineering Programme. Uppsala University School of Engineering, UPTEC IT 04 003, ISSN 1401-5749, 2004.

[Russell and Norvig, 2003] S. J. Russell and P. Norvig. *Artificial Intelligence: A Modern Approach*. Prentice Hall, Upper Saddle River, New Jersey, second edition, 2003.

[Saab Systems, 2002]. *Scenario Background*. Work Material, Saab Systems, 2002.

[Saab Systems, 2002a]. *Gammia Scenario: Force Listing*. Work Material, Saab Systems, 2002.

[Saab Systems, 2002b]. *Extract from 10th Brigade Combat plan 190800Z AUG 06*. Work Material, Saab Systems, 2002.

[Sachs, 1995] Patricia Sachs. Transforming Work: Collaboration, Learning, and Design. In *Communications of the ACM*, Vol. 38, No. 9, 1995, pp. 36-44, 1995.

[Savage, 1954] Leonard J. Savage. *The Foundations of Statistics*. John Wiley & Sons, New York, 1954.

[Shafer, 1976] Glenn Shafer. *A mathematical theory of evidence*. Princeton University Press, 1976.

[Schmitt and Klein, 1999] John Schmitt and Gary Klein. A Recognitional Planning Model. In *Proceedings of the 1999 Command and Control Research and Technology Symposium*. Newport, Rhode Island: Naval War College, 1999.

[Schubert, 2003] Johan Schubert. Evidential Force Aggregation In *Proceedings of the Sixth International Conference on Information Fusion*, Cairns, Australia, 8-11 July 2003. International Society of Information Fusion, 2003, pp. 1223-1229.

[Sidenbladh and Wirkander, 2003] Hedvig Sidenbladh and Sven-Lennart Wirkander. Tracking random sets of vehicles in terrain. In *The 2nd IEEE Workshop on Multi-Object Tracking*, Madison, WI, USA 2003.

[Smith, 1995] Robin Smith. Logic. In Barnes, editor, *The Cambridge Companion to Aristotle*. Cambridge University Press, Cambridge, New York, 1995.

[Smith, 2002] Edward R. Smith. Effects Based Operations: Applying Network Centric Warfare to Peace, Crisis, and War. U.S. DoD, 2002.

[Smithson *et. al.*, 1999] Michael Smithson, Thomas Bartos, and Kazuhisa Takemura. Human judgment under sample space ignorance. In Gert de Cooman, Fabio G. Cozman, Serafin Moral, and Peter Walley, editors, *Proceedings of the First International Symposium on Imprecise Probabilities and their Applications*, pages 324–332. Gent University, 1999.

[Stefani *et. al.*, 2002] Raymond T. Stefani, Clement J. Savant, Bahram Shahian, and Gene Hostetter, *Design of Feedback Control Systems*, 4th edition, Oxford University Press, 2002.

[Steinberg and Bowman, 2001] Alan N. Steinberg and Christopher. L. Bowman. Revisions to the JDL Data Fusion Model, in D. L. Hall, J. Llinas, editors, *Handbook of Multisensor Data Fusion*, CRCPress, New York, 2001.

[Suzić, 2003] Robert Suzić. Representation and Recognition of Uncertain Enemy Policies Using Statistical Models. In *Proceedings of the NATO RTO Symposium on Military Data and Information Fusion*, Prague, Czech Republic, October 2003.

[Suzić, 2003a] Robert Suzić. Generic Representation of Military Organisation and Military Behaviour: UML and Bayesian Networks. In *NATO RTO Symposium on C3I and Me&S Interoperability*, Turkey, October 2003.



[Suzić and Wallenius, 2005] Robert Suzić and Klas Wallenius. Effects Based Decision Support for Riot Control: *Employing Influence Diagrams and Embedded Simulation*. In *proceedings of MILCOM 2005*, Atlantic City, NJ, October 17-20, 2005.

[Swedish Armed Forces, 2001] *Facts and Figures: The Swedish Defence 2000 - 2001*. Information Department of the Swedish Armed Forces, Stockholm, Sweden, 2001.

[Swedish Armed Forces, 2004]. *C OPIL Operationsplan Euforia för EU:s militära operation ALTHEA i Bosnien-Hercegovina*. 01 800:76778 8. OPIL, Högkvarteret, Swedish Armed Forces, 2004. In Swedish.

[Swedish Army, 1995] *Armereglemente del 2 TAKTIK*. Försvarets bok- och blankettförråd, Försvarmakten, Sweden, 1995. In Swedish.

[Thunholm, 2003] Peter Thunholm. *Military decision making and planning: towards a new prescriptive mode*. PhD thesis. Dept. of Psychology, Stockholm University, Sweden, 2003.

[Tversky and Khaneman, 1981] Aamos Tversky and Daniel Khaneman. The Framing of Decisions and the Psychology of Choice. In *Science*, vol. 21, 1981.

[US Army, 1997] *Field Manual (FM) 101-5. Staff Organization and Operations*. Department of the Army, Washington, DC, 1997.

[USJFCOM, 2005] *Joint Forces Command Glossary*. Website of US Joint Forces Command. Retrieved in September 2005. [www.jfcom.mil/about/glossary.htm#A](http://www.jfcom.mil/about/glossary.htm#A)

[Wagenhals *et. al.*, 2003] Lee W. Wagenhals, Alexander H. Levis, and Maris “Buster” McCrabb, Effects-Based Operations: A historical perspective for a Way Ahead. In *Proceedings of 8th International Command and Control Research and Technology Symposium*, National Defense University, Washington, DC, June 17-19, 2003.

[Wallenius, 2000] Klas Wallenius. A Network Centric Info-Structure for the Swedish Armed Forces. In *Milinf 2000*, Enköping, Sweden, 2000.

[Wallenius, 2000a] Klas Wallenius. Use of Modern Information Technology: WASP - A Common View of the Situation. In *Technet*

*Europe, 21st AFCEA Europe Symposium & Exposition*, Prague, the Czech Republic, 2000.

[Wallenius, 2002] Klas Wallenius. A Generic Model of Management and Command and Control. In *Proceedings of 7th International Command and Control Research and Technology Symposium*, Loews Le Concorde Hotel, Quebec City, QC, Canada, September 16-20, 2002.

[Wallenius, 2003] Klas Wallenius. DISCCO – Decision Support for Command and Control. In *CIMI 2003*. Enköping Sweden, May 20-22, 2003.

[Wallenius, 2004] Klas Wallenius. On support for situation awareness in command and control. In *Proc. Seventh International Conference on Information Fusion (FUSION 2004)*, Stockholm Sweden, June 28 to July 1, 2004. In press.

[Wallenius, 2004a] Klas Wallenius. DISCCO: Generic Support for C2 and Decision-Making. In *Proceedings of 2004 Command and Control Research and Technology Symposium*, San Diego, California, June 15-17.

[Wallenius, 2004b] Klas Wallenius. *Generic Support for Decision-Making in Management and Command and Control*. Licentiate thesis, Department of Numerical Analysis and Computer Science, Royal Institute of Technology, Stockholm, Sweden, May 2004.

[Wallenius, 2005] Klas Wallenius. Decision Support for Effects-Based Operations. In *Proceedings of Second International Conference on Military Technology*. Stockholm, Sweden, October 25-26, 2005.

[Walley, 1991] Peter Walley. *Statistical Reasoning with Imprecise Probability*. Chapman and Hall, 1991.

[Wiener, 1948] Norbert Wiener. *Cybernetics, or control and communication in the animal and the machine*. John Wiley & Sons, New York, 1948.

[Wigren, *et. al.*, 1996] Torbjörn Wigren, Egils Sviestins and Henrik Egnell. Operational multi-sensortracking for air defence. In *Proc. First Australian Data Fusion Symposium*, pp. 13-18, Adelaide, Australia, 1996.

[Woodcock *et. al.*, 1993] Alexander E. R. Woodcock, Loren Cobb, and John T. Dockery. Cellular Automata Models of Combat in J.T.

Dockery, and A.E.R. Woodcock, editors, *The Military Landscape: Mathematical Models of Combat*. Abington, Cambridge: Woodhead Publishing Company, Ltd, 1993.

[Worm, 2002] Arne Worm. *On Control and Interaction in Complex Distributed Systems and Environments*. Linköping Studies in Science and Technology, Dissertation No. 664, Linköping University, Linköping, Sweden. ISBN 91-7219-899-0, 2002.

[Yi, 2002] Choong-ho Yi. *Modelling Object-Oriented Dynamic Systems Using a Logic-Based Framework*. Linköping Studies in Science and Technology, Dissertation No. 774, ISBN 91-7373-424-1, Linköping University, Sweden 2002.

[Yufik and Cunningham, 2001] Yan M. Yufik, W. B. Cunningham. Towards Dominant Battlespace Comprehension in Network Centric Warfare In *6th International Command and Control Research and Technology Symposium*, U.S. Naval Academy, Annapolis, Maryland, 19-21 June 2001.

[Åström, 1968] Karl Johan Åström. *Reglerteori*. Almqvist & Wiksell / Gebers Förlag, Stockholm, Sweden, 1968. In Swedish.







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