# Support for Situation Awareness in Command and Control

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**Abstract** – *To support the work by military commanders and staffs, this paper presents a classification of different support tools, including Command Support, Decision Support, Multi-Sensor Fusion, and Information Fusion. Together, these tools would facilitate shared Situation Awareness, including knowledge of friendly as well as hostile, forces on different levels of abstraction. Externalizing the situation awareness, a Common Situation Model enables the integration of these support tools but also the collaboration between individuals. The main emphasis is thus on the ontology of this model, representing the language by which the situation may be described. Consequently, a UML Class Diagram is proposed that expresses a conceptual model of the Command and Control domain. This model is generic since it could be adapted to different situations.*

**Keywords:** Command and Control, Decision Support Information Fusion, JDL Model, Ontology, Situation Assessment, Situation Awareness

## 1 Introduction

The concept of *Situation Awareness* (SA) is of great interest when studying how the work of military staffs and commanders could be supported in their work in planning and making decisions regarding subordinated resources.

To this end, we will define *Command and Control* (C2) to represent the work performed by commanders. Then we give an overview on how SA could be defined and modelled, and also propose a classification of support tools, including Command Support, Decision Support, and Data Fusion, that could enhance SA in the perspective of C2.

SA is, however, a mental state and cannot be directly interacted with by use of technology. The *Common Situation Model* hence provides means to externalise SA to, in turn, facilitate sharing it over a computer network and interacting with it through the different support tools.

Since a purposeful structure of this model is vital for the development of the support tools, the main concern of this paper is to describe the *ontology* of the situation model. 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 [1]. Hence we refer to the first meaning by defining the language used to externalise SA in a data model.

The role of ontologies has also recently come into focus in the Data Fusion community, e.g., by [2] who describes a methodology and a building environment to maintain domain specific ontologies, and by [3] who suggest a slightly different approach by describing an ontology for SA that is *generic*, since it could be instantiated for different domains. Our approach is more related to the latter, in that it defines a conceptual model of C2 to represent the ontology. First presented in [4], this model represents classes of entities, and the relations between them, that would be common for all cases in the C2 domain. Including resources, roles, services, tasks, and plans, these classes may then be instantiated for specific command levels and positions in the military organization.

The object-oriented *UML* (Unified Modelling Language) will be used to represent the model. See [5] for a further introduction to the UML and how to use it in a design process.

## 2 Command and Control

As argued by [4], the work of commanders and staffs could be seen as a breakdown of abstraction. Tasks assigned on a higher level of abstraction are implemented by assigning tasks to resources on a lower level of abstraction. To optimize the use of the subordinated resources, different alternatives to this solution should be considered before the decision is made. Extending a definition given in [4], we propose the following definition of C2, to denote this work:

*C2 is the act of fulfilling a task assigned to an organization in terms of designing, evaluating, approving, 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 fulfil these subtasks.*

This definition emphasizes that future military organizations will be dynamic and flexible. Depending on the situation and current tasks, new units will be assembled to meet the requirements. Also, novel chain-of-command structures may arise, allowing for different, multiple, or virtual, organizations. For example, [6] investigate such multiple organization trees that change over the different phases of the mission.

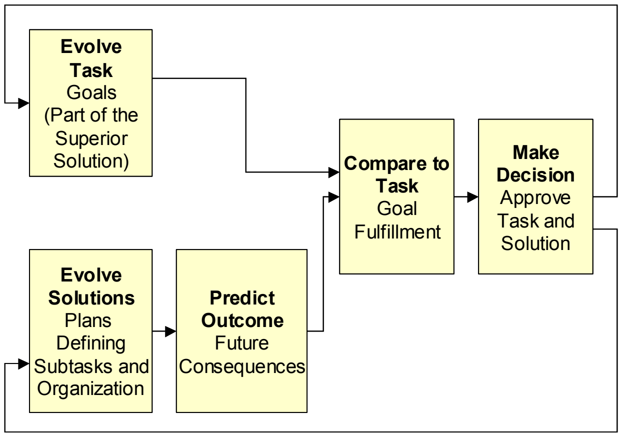


Fig.1. The generic decision-making process.

Also emphasized in the definition, is the fact that C2 is an instance of decision-making. There are different descriptive and prescriptive models representing how this decision-making is performed and should be performed [7 - 9]. The suggested generic decision-making process in Fig. 1 aims at representing these different models from a conceptual perspective.

From this point of view, 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 the 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 fulfil the goals, and hence could be approved. At execution, again these steps are iterated, assessing the currently approved plan and comparing it to its alternatives, as time passes and new information is gained. In this sense the model in Fig. 1 is *dynamic.*

## 3 Situation Awareness

Endsley's model [10] defining SA is the one that seems most commonly accepted. According to this model, SA refers to knowledge of a dynamic environment, while more static knowledge, such as on rules and procedures, is excluded from the term. According to the 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.

Endsley's definition of SA has, however, been criticised for its strictly individual perspective. For example, [11] maintains that SA should be defined in a perspective of interaction between individuals, artefacts, rules and culture, as a system that makes decisions. Hence, [11] 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."*

This latter definition indicates that there is a part of SA that cannot be derived from the reality in a strictly objective sense. Instead, it 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 are involved, these definitions should be based on agreements between the agents, or at least communicated amongst them.

Still, there remains an objective part of SA, since independent agents would reach at least some similar knowledge when observing the same entities in the reality. Presumably this objective part is more prevalent in SA Level 1, dealing with physical elements in the environment, whereas the higher levels of SA, comprehending the meaning of these elements are more subjective.

We see two reasons why SA should be shared between different positions in the organisation: (1) With respect to the objective aspect of SA, sensor and processing resources could be utilized more efficiently since the data from them could potentially be useful for more than one decision-maker. (2) Regarding the subjective aspect, it is essential that the constructed elements of SA can be shared to promote collaboration between the different decision-makers.

## 4 The Levels of Data Fusion

Achieving SA is a mental activity that primarily relies on the human mind and the human senses. Yet, people have always striven to enhance SA by integrating data from different external sources (such as human observers and sensor devices) and combining these with stored knowledge (as in present days from books and databases). The methods supporting this integration are known as Data Fusion, defined as *"... the process of combining data or information to estimate or predict entity states."* [12]

The revised JDL Data Fusion model, as reviewed by [12], depicts five interacting levels of Data Fusion: *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 or estimated or predicted actions. *Level 4,* Process Refinement, is the adaptive management of sensor resources and of the Data Fusion processing.

Although the definition above does not say anything about the usage of the output of Data Fusion, the significant similarities between Endsley's model of SA and the JDL model imply that the purpose of Data Fusion is to support SA. The output of Data Fusion is, however, not SA, since SA is a mental state. Instead we argue that the purpose of Data Fusion, whether performed completely manually or with the support of computers, is to maintain a *situation model* 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 for example by a Human/Computer Interface, as is also suggested in the JDL model.

A distinction is sometimes made between *Multi-Sensor Data Fusion* (corresponding to Level 0 and especially 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 [13].

Although the distinction between the sensor data and elaborated information, as being the sources for the two different categories of Data Fusion, is rather vague, we believe that this division is also practical from other points of view: (1) When estimating object states representing physical phenomena by Multi-Sensor Data Fusion, on the one hand, there is an objective truth that could be sought without much interaction with and between operators. As previously argued, the higher levels of SA supported by Information Fusion are, on the other hand, much more subjective in character, and there is also an element of active construction that needs to be considered. (2) The model of the world, by which the different entities could 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, or the ontology, becomes much more complex. (3) As argued by [2], Information Fusion also involves a component of hierarchy, due to the vertical organization of military entities, and to multiple levels of abstraction. (4) Further argued by [2], higher-level Data Fusion emphasizes symbolic, rather than numeric, reasoning.

## 5 Complete SA in the Context of C2

In Fig. 2, we give an interpretation of what SA is in the context of C2. In this perspective, SA should include 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 states of other elements of the same, friendly, affiliation should be known by sharing information. The states of elements of other, hostile, affiliations could on the other hand only be assessed. SA on hostile elements achieved by such assessment should, however, also be shared among friendly elements.

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

(1) *SA on Physical Entities* includes perceived physical resources, such as vehicles, soldiers, weapons, and sensors, and the estimated states of these elements.

(2) *SA on Friendly Decisions.* Following the definition of C2 given in Section 2, these encompass decisions on the organization, and decisions on tasks (or intentions) for this organization. The organization is a multiple and flexible hierarchy, with physical resources on the lowest

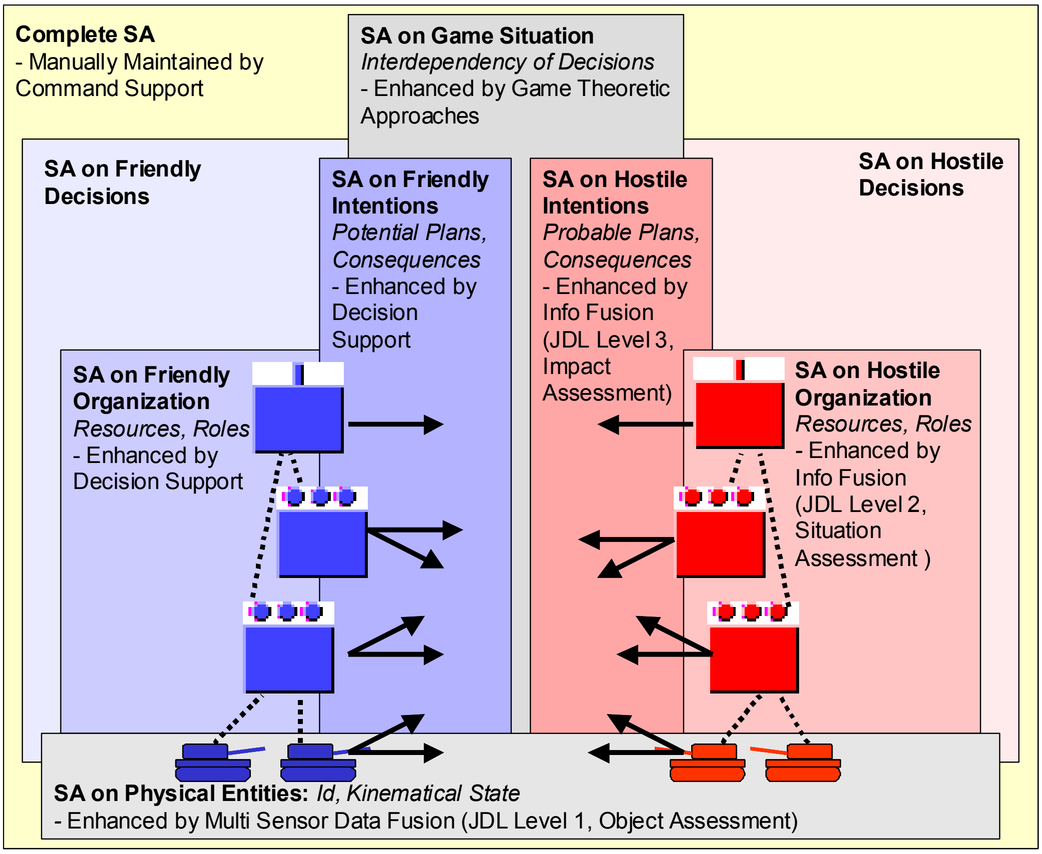


Fig. 2. Complete SA for the C2 case, enhanced by different support tools

level that have roles in superior, abstract, resources, such as platoons, companies, brigades, and task forces. Conforming to the generic decision process in Fig. 1, the SA on intentions includes potential plans with sub goals and the assessed consequences and utility of these plans. It also includes knowledge of which of the potential plans are currently approved, thus representing the actual decision.

(3) *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.

(4) *SA on Game Situation.* The assessment of the hostile decisions ultimately depends on friendly decisions, and vice versa. This game situation, where one agent has an assessment of the other agent's intentions, which in turn has an assessment of the first agent 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.

# 6 Technical Support to Facilitate Complete SA

Also, Fig. 2 suggests a classification of different support tools that may be used to facilitate the SA. As SA is a mental state distributed among decision-makers, there need to be means to represent it by use of technical artefacts. Hence by *Command Support* it is possible to maintain and interact with a *Common Situation Model*, which, in turn, would represent the complete SA.

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

(1) Multi-Sensor Data Fusion enhances the manual inference of the states of physical resources, friendly as well as hostile. This is a mature area, with many implementations, at least for the case of objects in the air and the sea, as in the examples provided by [14, 15]. Physical resources on the ground are however more difficult to track. One approach is being developed by [16].

(2) Information Fusion, JDL Level 2 concerning Situation Assessment, supports the inference of hostile organization. An example if this is presented by [17].

(3) Information Fusion, JDL Level 3 concerning Impact Assessment, supports the inference of hostile intentions. [18, 19] both develop approaches based on knowledge of the enemy's needs and doctrine, combined with observations of the behaviour of the hostile units.

(4) Decision Support enhances the work of making our own decisions on organization as well as on tasks. For example, [20] suggest that agent-based simulations should be generated from the situation model. Hence, potential plans could be assessed by the prediction of the future states of the situation

(5) Support based on *Game Theory* enhances the SA of the game situation. Presently, not much work has been performed in this area. [21-23] have however suggested some approaches.

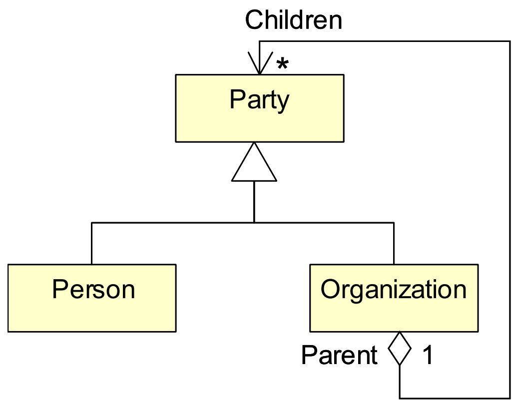


Fig. 3. An example of class diagrams, depicting the Party Composition Structure.

# 7 A Class Diagram representing the Ontology of SA

## 7.1 Resources

From the generic decision-making process, we recognize that the concepts of tasks and solutions should be essential in the Common Situation Model. In defining the ontology for this model, we start, however from a slightly different point of view, by modelling the resources that may be assigned to perform these tasks as part of a solution on a superior level. According to the discussion on flexible organization in Section 2, we also acknowledge that resources may be dynamically subordinated to multiple organizations.

In the *Party Composition Structure* (Fig. 3), organizations as well as persons, by both being subtypes of Party, could be children of an organization [5]. This recursive party composition structure is of great interest to us, since it can model an organization of any depth, and since it treats persons and organizations in a similar manner. Changing the name from 'Party' to *Resource* would, however, place greater 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 3. 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, and route, should also be subclasses of Abstract Resources.

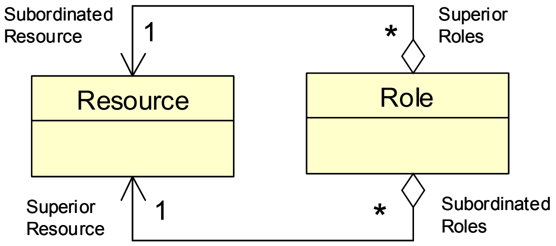


Fig. 4. Roles permit memberships to multiple organizations.

### 7.2 Roles

One of the main issues is that there must be means to model multiple and dynamic organizations. By means of the *Accountability Pattern* [24], a local sales office in a worldwide company could have accountability both to the local subsidiary and to the global sales organization. We follow this design pattern, but the name of the connecting class is changed to better align with C2 vocabulary. Hence, we let the *Role* class represent any directed connection defining a vertical relationship between two resources, see Fig. 4. As such it could be seen as a membership of, or subordination to, a superior resource, or the means to represent aggregation. By letting each resource have any number of roles, one could consequently model multiple organizations.

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, modelling that, for instance, a unit is located within a certain area.

Different roles may entail different kinds of privileges and obligations in accordance with prevailing explicit or tacit rules and regulations. 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 *Supporting Role* suggests a weaker relationship than an *Under Command* role.

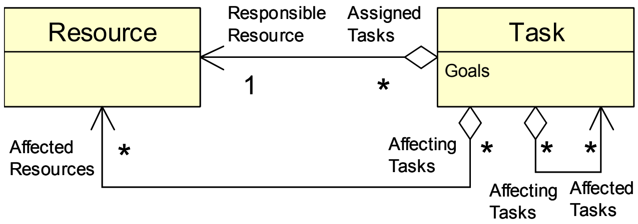


Fig. 5. A Task could be assigned to a Resource, and could affect other Resources as well as other Tasks.

### 7.3 Tasks and Assignments

Assigning a *Task* to a Resource represents a decision that the Resource is expected to achieve some *Goals*, see Fig. 5. These goals encompass different kinds of external and internal expectations. Negative goals, representing *Restrictions*, are also encompassed in this attribute. Tasks assigned to Resources of hostile affiliation may be used to express what is known of the enemy's activities and intentions.

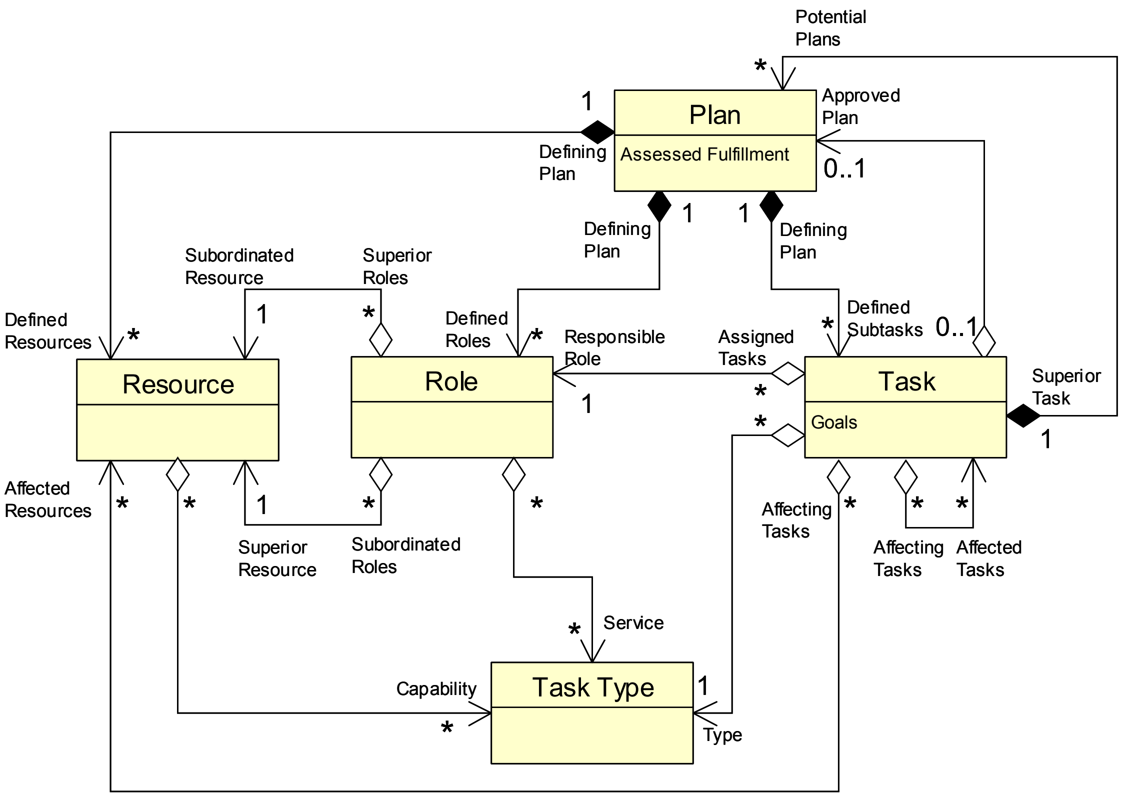


Fig. 6. The Concluding Model.

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 a Resource, or another Task, that is the subject of this defence, such as a certain area, a radio station, or some activity.

Tasks could be divided into three categories, *Perception Tasks*, having to do with gathering of data on states in the reality, *Cognitive Tasks*, dealing with processing these data, and making decisions, and *Effectuating Tasks,* having to do with changing states of the reality.

### 7.4 Task Types, Capabilities and Services

To model virtual organizations, it is of interest to represent the fact that different subordinated roles give different rights for the superior resources to assign tasks to the subordinated resources. Although defining different role types, as discussed in Section 4, may solve parts of it, the lower part of the Class Diagram in Fig. 6 depicts further elaboration on the issue of restricted rights. By introducing a Task Type class, it is possible to model the *Capabilities* of a resource, representing which types of tasks a resource could be assigned. Furthermore, it is possible to model the *Services* offered through a role, representing which of the capabilities the superior resource is allowed to utilize.

To enable this handling, it is necessary to keep track of the role to which the task is assigned, rather than the resource, as was the case in Fig. 4. Hence, according to Fig. 5, there is a direct association between Task and Role rather than between Task and Resource.

### 7.5 Plans

A Plan represents the solution for a superior task. Several alternative solutions could, 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 subtasks that could 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 Fig. 6 also 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 rhombuses, to emphasize that there must be one and only one ancestor. Consequently, it is by a plan that a resource, a role, or a task comes in existence.

To further facilitate the generic decision-making process depicted in Fig. 1, the attribute *Assessed Task Fulfilment* has been associated to the Plan class. To represent the decision, one (at most) of the potential solutions could be selected, thus gaining the status of being the *Approved Solution.*

### 7.6 Two Examples

We will now finish the presentation of the ontology by giving two small examples of how it could be applied to describe situations to support SA.

The first example, presented in Fig. 7, illustrates a resource that has two different roles. 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.

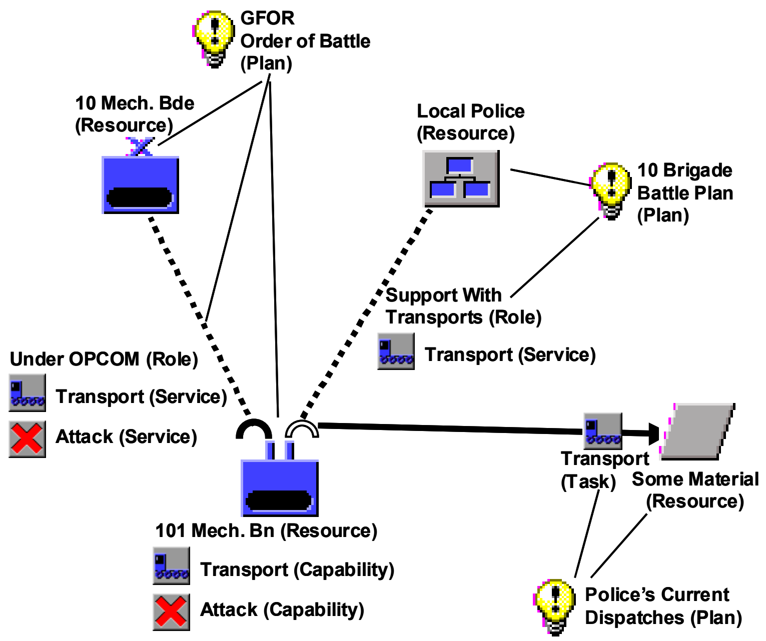


Fig. 7. An example of a Battalion with two different roles.

The Brigade Battle Plan further states that there is a local police organization. Expressed by the Transport service, the Battalion is ordered 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.

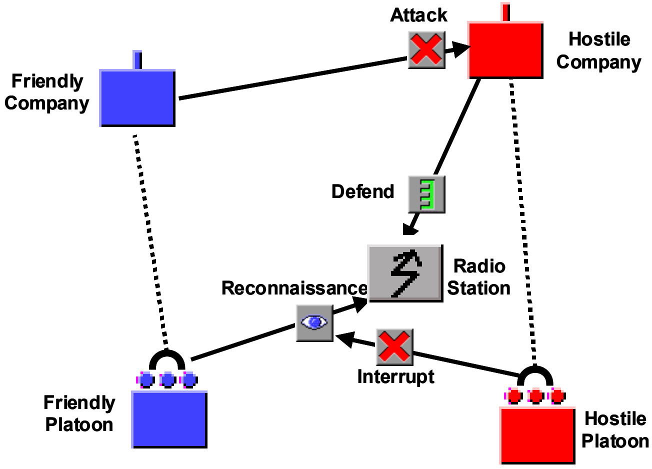


Fig. 8. An example of a situation with two opponent forces expressed on two levels of abstraction.

The second example, illustrating opponent forces represented on different levels of abstraction, is shown in Fig 8. The friendly company, in this example, is assigned the task of attacking 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.

## 8 Conclusions

To illustrate the ideas of different kinds of support tools interacting with the Common Situation Model, we have developed a prototype of a system named *DISCCO* (Decision Support for Command and Control). Fig. 8 shows a screen shot from one of the Command Support Tools that provides a hierarchical view of the organization. Other views by which it is possible to interact with the Situation Model include time views and geographical views.

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

By defining a very general relation class, the approach proposed by [3] places more emphasize on the lateral relations between objects in the situation. The differences between these two models need to be considered in the future development. The time aspect and the dependencies

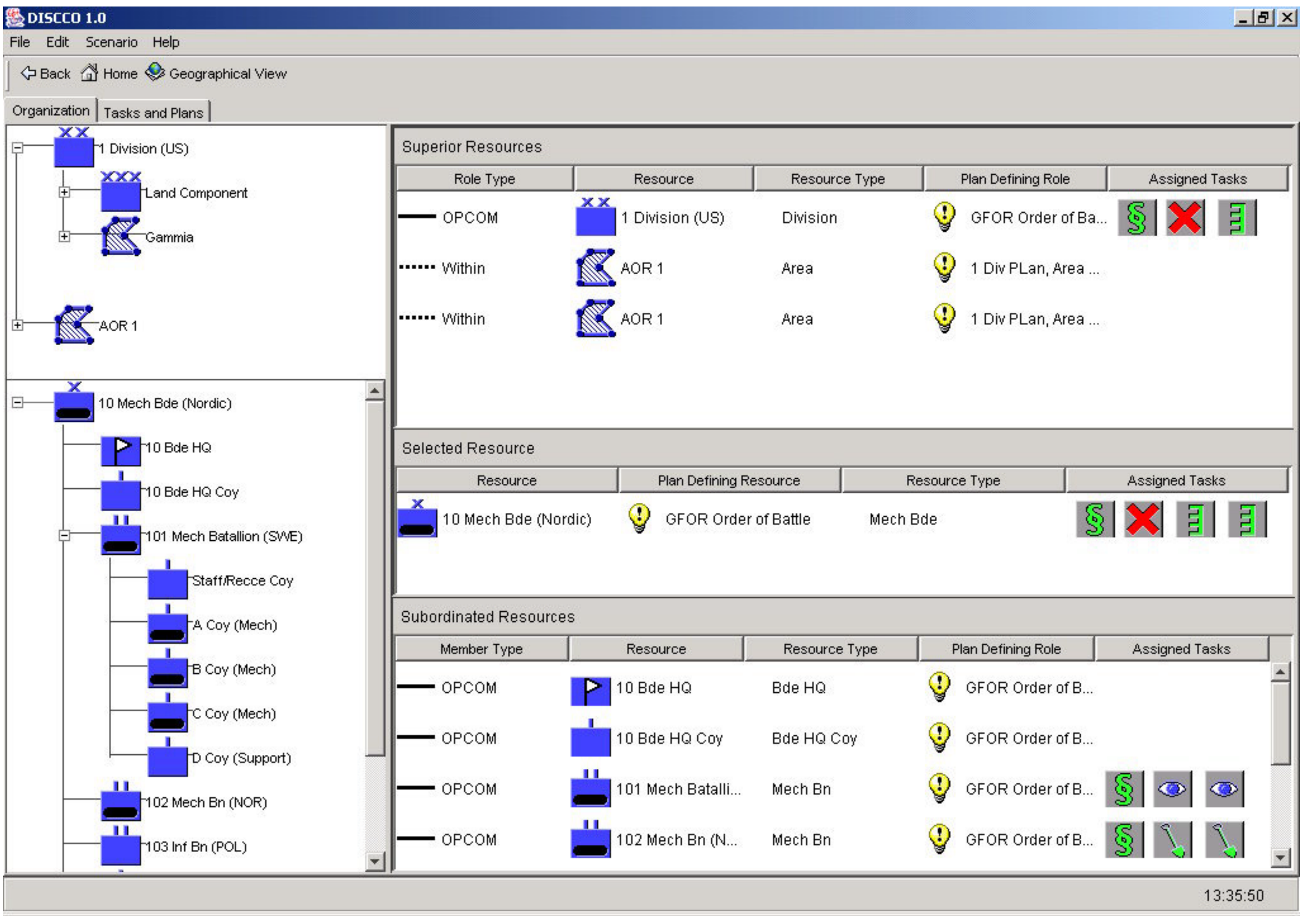


Fig. 8. An example of a hierarchical tree view expressing the organization.

between different tasks also need further emphasis.

Another important aspect when modelling the hostile elements is the concept of uncertainty. As uncertainty is difficult to represent by the UML, [25] suggests that it should be combined with Bayesian Networks. Further investigating the uncertainty area, [23] define Bayesian games to solve the dependencies between friendly and hostile decisions.

Nevertheless, by representing the ontology of a Common Situation Model, the model suggested in this paper will admit the flexible integration of different support tools. Hence, future development of Command Support, Decision Support, Multi-Sensor 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.

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[2] `http://www.saabtech.se/`

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