A Generic Model of Management and Command and Control

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Abstract

The design of general support systems for military activities would greatly facilitate co-ordination and co-operation between different positions throughout the organization, increase flexibility in solving unknown tasks, and provide more cost-effective solutions. Command and Control (C2), as well as other types of business and military management, show generic features that should be emphasized when developing such general systems. Based on a definition of C2 and discussions on different aspects of organization and decision-making, a generic model of C2 is suggested. To provide informative and precise input to the design process, the object oriented Unified Modeling Language (UML) is used to represent the model.

1. Introduction

Most technical systems to support military activities are designed with specific work tasks in mind. This traditional bottom-up approach to system design has its place since there are so many different activities going on in the military organization. There are, admittedly, large differences between for instance calculating missile trajectories, navigating large battle-ships, and supplying thousands of people with clean underwear. Still there ought to be much in common in the work of *managing* these various 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]. Much will be gained if these results could be exploited by designing more general support systems that can be used in different positions throughout the military organization:

- First of all, such a common support system will greatly facilitate co-ordination and co-operation between units throughout different parts of the organization. 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 [Wallenius, 2000].

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- Increased flexibility is another argument. Flexibility is the key to meeting the unknown threats of the future. If one relied on general tools and methods rather than on specialized ones, one would be better prepared to solve new tasks. Also, a common support system will encourage establishment of temporary organizations to further support flexibility.
- Finally, development efforts will be more cost effective since there would be a greater focus on software reuse. In addition, reuse of training and experiences in using the system will 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.

For all these reasons we advocate a top-down approach of designing support systems as a complement to the prevailing bottom-up approaches.

Communicating with domain experts is one of the biggest challenges when designing computer systems [Fowler, 1999]. Our reason for using the *UML (Unified Modeling Language)* is to go from discussing C2 using natural language and ad hoc graphical notation, to presenting a model with a more precise meaning. As such, the presented model will provide an informative link between the C2 community and the design process of C2 support systems. Object-oriented methods also provide means to increase reuse of design efforts, including the concepts of patterns and the generalization/inheritance relation. 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.

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 driver in modeling organizations [Cohen, 1998]. He 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.

We thus advocate that the work of commanders in different positions in the military organization could, and should, be described in a generic fashion using object-oriented modeling. In this paper we suggest such a model of C2 to serve as the input for design of generic and common C2 support systems. To this end, a definition of C2 is given to attain a more precise meaning of the extent to which the model is generic. Different perspectives of organization and decision-making are also discussed to increase the generality of the model.

However, the key issue when describing C2 in generic terms is to disregard which kind of tasks that are solved and which kind 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. Hence C2 becomes very similar to management in any kind of organization, and consequently, the derived support tools will work even outside the traditional military C2 domain.

2. **The definition of Command and Control**

Although very common in the military literature, there is no agreement on what C2 really means [Roman, 1996]. The definition given by Coakley seems, however, to be most broadly in use:

> *"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."* [Coakley, 1991]

As our aim is to design tools to support co-operation and co-ordination between different parts of the organization, we make the reflection that C2 cannot have this individual perspective of a single executive making decisions. Instead we need more focus on the very purpose of C2 as something that is performed in a system of individuals. There must be a purpose for the work of the thousands of commander included in any nation-wide military organization.

Clearly this purpose has to do with effectively utilizing the forces to achieve something and that no single individual could possibly perform this work. The decision made by the 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.

The capability of performing C2 is obviously limited to the cognitive capacity of the commanders. There have been several approaches to quantifying this capacity. Among these, Yufik and Cunningham see resource allocation as a combinatorial problem [Yufik and Cunningham, 2001], and Anthony has found regularities regarding the scaling relationships between different echelons within the U.S. Forces [Anthony, 1999].

Using the approach of *Work Domain Analysis* [Rasmussen, 1993], the organization could be seen from different *levels of abstraction*. The Parliament and the Government deals 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 much more suitable to describe the task of commanders:

> *C2 is the act of fulfilling a task assigned to an organization, in terms of designing a plan constituted by subtasks on a lower level of abstraction, and designing an subordinated organization constituted of available resources on a lower level of abstraction, to fulfill these subtasks.*

3. Networked organizations

3.1 *The Future Military Organization*

The military organization has traditionally been defined as a rigid tree-structure in which every organization unit has one and only one parent unit. Also, it has always been very strictly defined who is allowed to share information and to make decisions. Some researchers, such as for instance Dahlbom, argue that such rigid hierarchical organizations soon will be outdated [Dahlbom, 2000]. Young people currently growing up with the new information technology will get used to setting up their own goals from a free market of possibilities to act. According to Dahlbom, voluntary agreements on what to perform will be the norm, rather than receiving orders from the superior commander.

Taking the view of Dahlbom, it is often argued that the organization could be removed completely, seemingly making the notion of C2 obsolete. Still, as long as we believe that the owner of resources has the slightest possibility to decide how to utilize them, the work of C2 to change the level of abstraction will be necessary. It must, however, be acknowledged that the current trends will highly affect the view of what C2 is. We will thus investigate what might be called the *networked organization* from two perspectives.

3.2 *Tacit and Informal Organizations*

The first perspective that could be taken on networked organizations regards relaxation of formal doctrines. As the collection of decisions concerning tasks and subordinations represent the will of the commanders, it could be seen as a prescriptive model of what should happen in the reality. However, as is the case with all models, it cannot fit reality in all aspects. Any system that recognizes the model as being equal to reality is expected to be highly ineffective. Sachs emphasizes this by acknowledging the activity-oriented tacit view of work as being equally important as the organizational explicit view. The former, she 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 count 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 [Sachs, 1995].

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, but on the other hand one could 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 could be explicitly captured in orders and other documentation, but they could just as well be represented as tacit understandings between individuals.

3.3 *Dynamic and Multiple Organizations*

The other perspective of the changes implied by the new technology regards the requirement for dynamic and multiple organizations (which could still be very formal). As shown by Alberts *et al.*, the effect of weapon platforms, such as ships, tanks and aircraft, can be increased tremendously when carefully synchronized during a mission [Alberts *et al.*, 1999]. This requires some sort of organization of weapons and sensors, which may be different from the organization that controls the platforms. Borchert and Jones, for instance, investigate such multiple organization trees that also change over the different phases of the mission [Borchert and Jones, 1999].

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 could, 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 could rapidly be adapted to changes in the threat picture. Consequently the Swedish Armed forces have different chains of command for missions than for other issues [Swedish Armed Forces, 2001].

All these examples show the importance of our notion of C2 not assuming anything about a static organization. To this end, our definition emphasizes the fact that the organization is something that is designed dynamically. A resource may very well be subordinated on a long-term basis to one organization, and, concurrently, during shorter periods to one or several others.

4. Planning Models

4.1 *Classical Planning Doctrines*

Most often, the military organizations have prescriptive *planning models*, such as the Strategic Commanders Guidelines for Operational Planning, (GOC) [NATO, 1998], prescribing how C2 work should be managed. The purpose of these models, according to Thunholm, is 1) to act as check lists to capture earlier experiences on what should be considered in the planning process, 2) to help coordinating the planning work, since people are trained to act according to these models, and 3) to improve the quality of decisions [Thunholm, 2000].

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 action (COA)* 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 one to execute.

4.2 *Naturalistic Decision Models*

The suspected difference between prescriptive planning models and decision-making in reality has triggered research within the area of *Naturalistic Decision-Making*. Klein describes how experienced military commanders (but also how maintenance officers, design engineers, as well as paramedics) make decisions [Klein, 1989]. As Klein argues, there is no time to develop and evaluate several decision alternatives, as opposed to what is prescribed in the planning doctrines. 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 *Planning Under Time Pressure (PUT)* model [Thunholm, 2000] is built on the work of Klein, but also on findings from other areas, capturing human deficiencies to make rational decisions under high pressure. The PUT Model goes from a rather intuitive process, choosing among possible solutions on the conceptual level, to a more analytic process to develop one detailed COA.

4.3 *A Technical Perspective on the Planning Models*

Since we want our model of C2 to be generic in the sense that it should correspond to many different instances of C2, we do not need to take a position and select only one of these models. It would, on the contrary, be an advantage if our model could represent a union of all the descriptive and prescriptive planning models that have been mentioned. The difficulty with such a general approach is of course to avoid a model too complex to be useful. We argue, however, that the complexity could be reduced, since the perspective is slightly different from the planning models mentioned. The purpose of our model is to provide the baseline for development of technical support systems. Thus the perspective is technical and belongs to the information domain, rather than the psychological or sociological domains investigated by Klein and Thunholm.

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

1. From the 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 proceeds, the level of abstraction decreases in terms of increased number of subtasks and increased level of details in the requirements of these tasks.

2. 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 difference between plans and ideas, we only need to model the fact that several alternative plans may be evolved concurrently.

3. A task has external goals and restrictions, set according to its purpose in the superior plan. The goals and restrictions could 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 [Thunholm, 2000]. These internal requirements on the

task could technically be represented as goals for the task that are complementary to the external formulation of the task.

5. The Suggested Model

5.1 *Object-Oriented Modeling*

It would lead to far to give a full description of object-oriented languages and methods in this paper. The features of the UML techniques we use will, however, be explained briefly as they are introduced in the following sections.

In the subsequent sections, we will design a UML model according to the definition of C2 and to the previous discussions. By defining *use cases* to describe a generic planning process, we identify important entities with which the commanders interact. From these entities we are able to draw a *class diagram* showing the relations between the identified entities. Finally we give an *object diagram* to illustrate the model by an example situation.

The presented model is drawn from the conceptual perspective, concentrating on the concepts of the domain under analysis. This should, according to Fowler, be done with little regard to the software we have in mind [Fowler, 1999]. This is very important, since it allows us to discuss a concept, such as a "plan", without specifying whether it exits in a computer, on a paper, or tacitly represented in people's minds. Thus the model will be kept independent from technical solutions and hence more general.

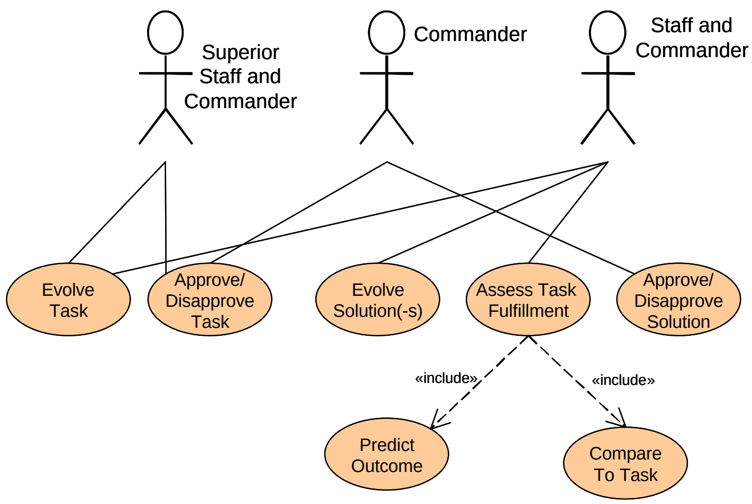

Figure 1. Use cases depicting a generic planning process.

5.2 *Use Cases Representing a Generic Planning Model*

Eliminate 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 could be an individual, a group of individuals, or another system.

We apply the technique of use cases to illustrate a planning model from the technical perspective, according to the discussions in section 4.3. 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.

The generic planning process depicted by the use case diagram in Figure 1 could be described as follows:

- The superior decision level has changed the task assigned 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, are 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 none of the solutions are 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 this planning process captures all of the models mentioned in section 4.3, under the condition that the actors and the different steps above are not taken to 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 1. There is however no room for such a detailed analysis in this paper.

5.3 *Modeling the Organization*

In the class diagrams *classes* of objects are identified. Two principal kinds of relationships between classes can be modeled: *associations* and *subtypes*. We use the "Party Composition Structure" [Fowler, 1999] to give an example of both of these relationships, see Figure 2. Indicated by the triangle, the classes Person and Organization are both subtypes of the class Party. This relationship is motivated by that a person and an organization show similarities that could be captured by a common super type. One such similarity is depicted in the diagram, in that both organizations and persons could 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 could have any number of children (by the '*').

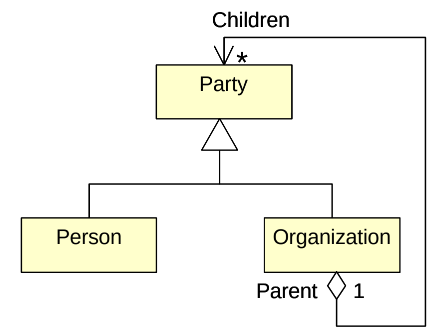

Figure 2. An example of class diagrams, depicting the "Party Composition Structure" [Fowler, 1999].

An object diagram provides an example of how objects could be configured governed by the definitions and restrictions given in the class diagram. Figure 3 depicts one such instance consistent with the class diagram from Figure 2. 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.

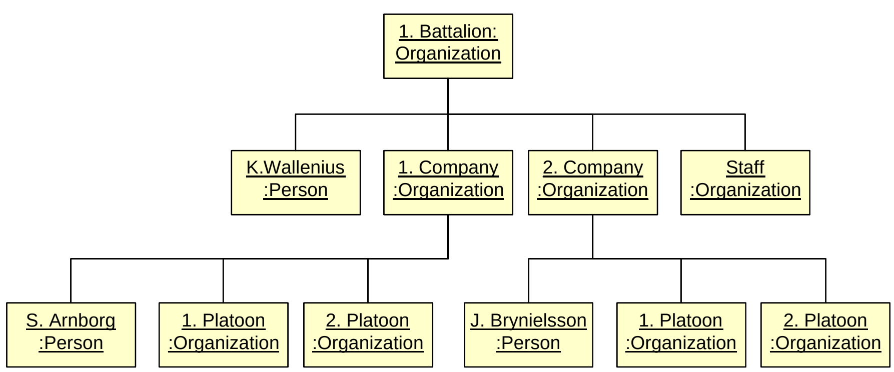

Figure 3. An object diagram exemplifying an organization of subordinated persons and organizations in accordance with the class diagram in Figure 2.

The recursive party composition structure is of large interest to us, since it could model an organization of any depth, and that it treats persons and organizations in similar manners. Changing the name from "Party" to "Resource" would, however, give a better emphasis on these similarities from our point of view. Real persons as well as whole organizations serve as resources when solving tasks on a certain levels of abstraction. We see that, apart from persons, there are also other types of physical entities, such as tanks, computers, and ammunition, which also ought to be represented by the Resource class.

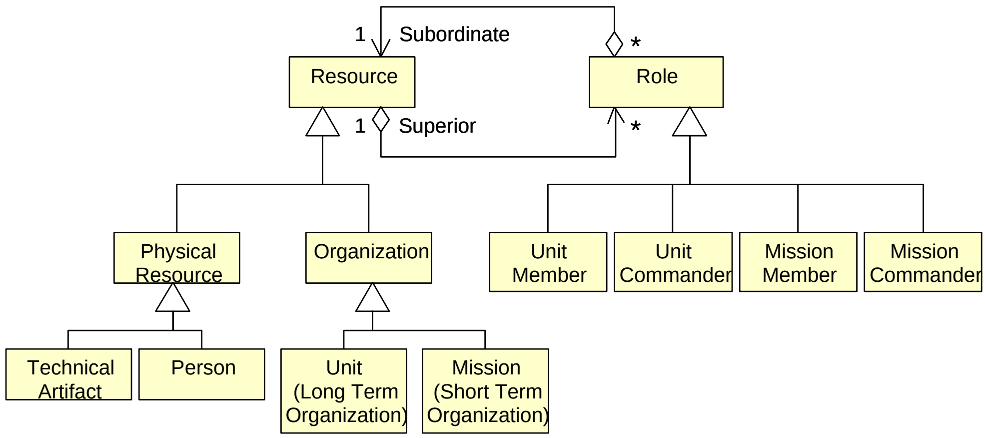

Figure 4. Multiple roles permit memberships to several organizations.

The main issue, though, is that there must be means to model also multiple and dynamic organizations. The design of a proper organization constitutes a prominent part of the C2 work to solve a task at hand, according to the definition and to the previous discussions. Following the *Accountability Pattern* [Fowler, 1997], we introduce the Role class representing a connection between two instances of a resource. By letting each resource having any number of roles, one could model any multiple organizations. In the class diagram, depicted in Figure 4, we see that resources can have any number of superior as well as subordinated resources.

Also depicted in Figure 4, we suggest that two types of organizations should be modeled: the Unit representing a long term organization prepared to solve many different tasks, and the Mission representing resources temporary organized to solve a specific task.

With different roles there may come different kinds of privileges and obligations following prevailing explicit or tacit doctrines. The meaning of “subordination” and “commanding” may be very dissimilar for different organizations. Although doctrines are not currently part of the suggested model we believe that introducing different types of roles might capture some of these issues. Hence four types of roles are depicted in the model, reflecting a long-term or a short-term membership, and whether that membership comes with command authorities or not.

5.4 *Introducing Tasks and Plans*

By defining the Role and Resource classes, and corresponding relations, we now have the means to model dynamic and multiple organizations of resources. To comply with the definition of C2, we also need means to represent tasks and plans, and how these relate to the organization.

A plan represents the solution for a 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. To be complete, however, a plan also should represent tasks that could be assigned to these roles. Making a decision on organization, tasks, and assignments, is then equivalent to *approving* a solution by selecting one of the potential solutions for further execution. Accordingly, it is the approved solutions that define the organization and the corresponding tasks.

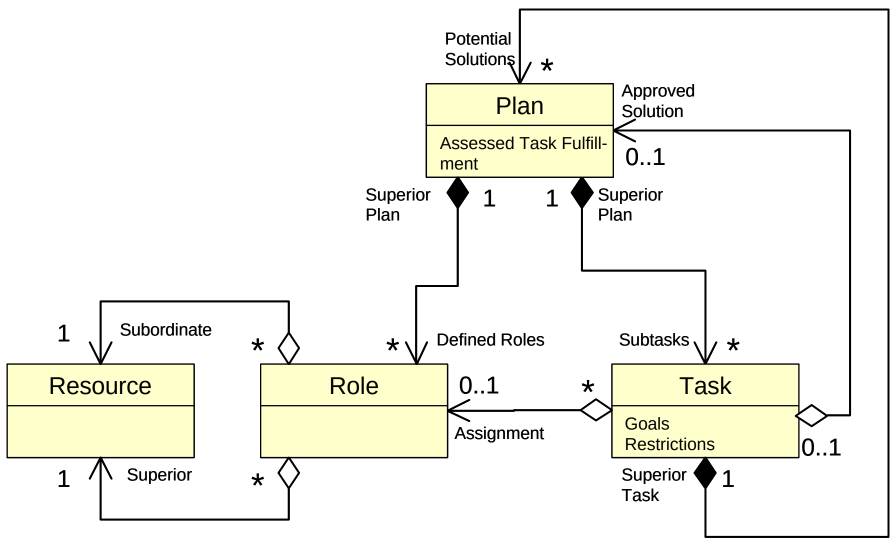

Figure 5. The suggested model. Plans represent potential solutions to tasks by defining roles, subtasks, and assignments.

Extending the model in Figure 4, the Class Diagram in Figure 5 captures all these further aspects. According to the diagram, instances of the Plan class define subtasks, roles of resources, 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 rhombs, 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 1, the attributes *goals* and *restrictions* 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 could be selected, thus gaining the status of *"Approved Solution"*.

6. An Example – the Object Diagram

Figure 6 depicts a fictive, and highly simplified, example of how a brigade unit belonging to the Swedish Armed Forces takes part in an international operation initiated by the United Nations. Decisions spanning from the political level down to the company level of the Swedish army are represented in this object diagram. The diagram does not give any examples of different potential solutions to the problem. Thus, only the *result* of the C2 work performed on different levels of abstraction is represented in this example.

The unit organization has been assigned long-term tasks to organize and prepare for different missions according to the main tasks of the Armed Forces, as defined by the Swedish Parliament in the Resolution on Defense. By the plans on the different levels, all units down to the companies thus have been defined.

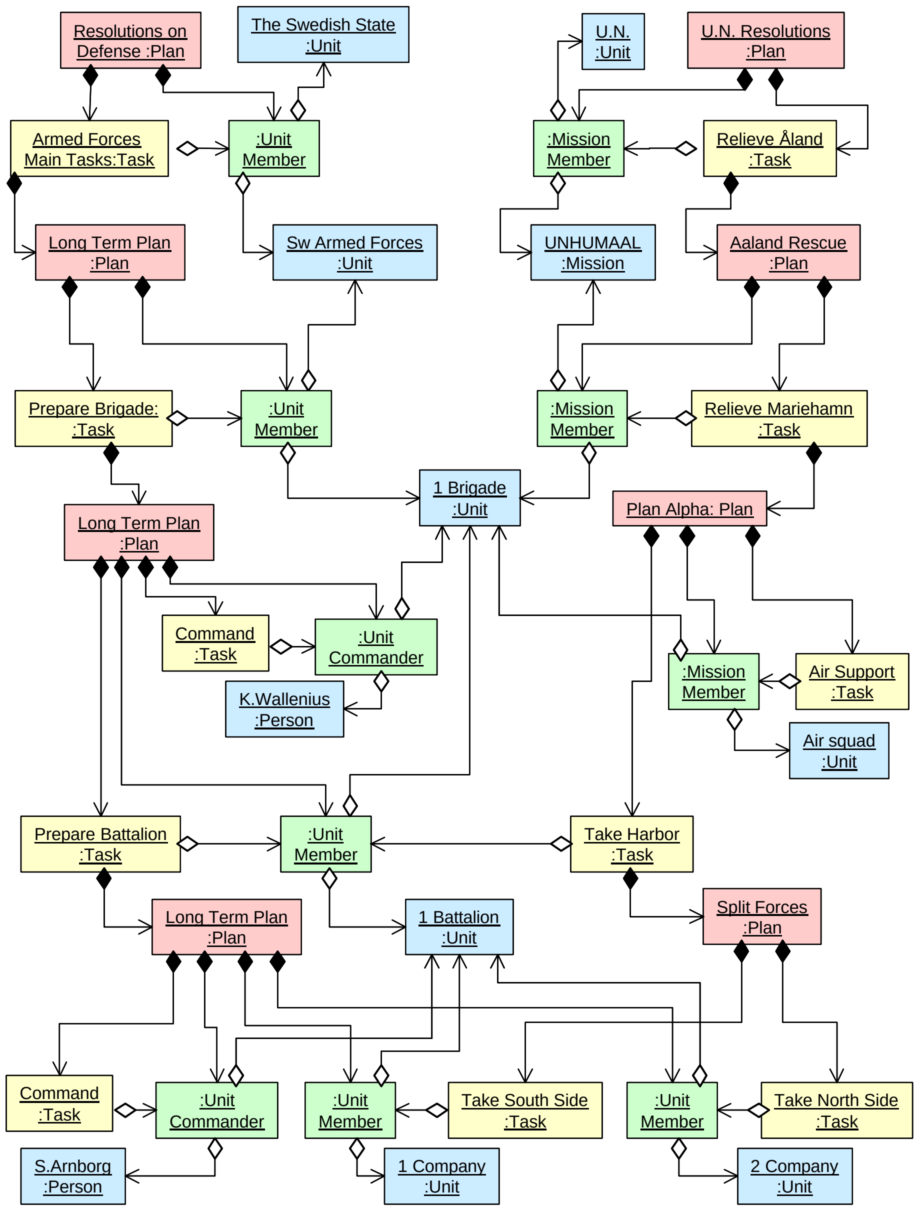

Figure 6. An object diagram providing an example of how the suggested model could be applied.

A decision to relieve the (demilitarized) zone of Åland from hostile terrorism actions is included among the resolutions of the United Nations. The establishment of a mission to restore humanitarian rights on Åland, UNHUMAAL, is a part of this decision. A plan how to achieve this is approved, in which it is defined that 1. Brigade is subordinated to the mission organization. The task for the Brigade, also according to the plan, is to relieve inhabitants of the main city of Mariehamn from hostage taking. By approving "Plan Alpha", it is decided that the solution to this task is to first take the harbor, currently occupied by terrorist forces. This mission is supported by an air squad, temporarily subordinated the 1. Brigade. On the Battalion level it is decided that one is to “Split Forces”, letting the 1. Company to take the north side of the harbor, and letting the 2. Company to take the south side.

7. Conclusions

The class diagram in Figure 5 provides definitions of classes and relations to describe the context of C2 from the various aspects that have been discussed in this paper. It also conforms to the generic planning process, as depicted in Figure 1. Together these two UML diagrams comprise the proposed generic model of C2.

The UML is a standardized modeling language in common use within the software development community. Using the UML thus gives a much more precise meaning to the model than does ad hoc graphical language. Consequently, it will be possible to derive an information structure from the model that will greatly facilitate the development of generic C2 support tools.

The reason why we claim that the proposed model and tools derived from it are generic, is that many different instances of C2 are represented. To summarize the discussions in the previous sections, we argue that the proposed C2 model captures the following dimensions of C2:

- Static and dynamic organizations. From the technical point of view, a static organization is a special case of dynamic organization. By allowing dynamic and multiple organizations, as the model does, 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 may include doctrines to represent such restrictions, providing the means for security management.

- Explicit and tacit organizations. In the suggested model 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 hope is that we may 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 software services performing parts of the C2 work based on artificial intelligence. However, to facilitate the substantial part of the tacit domain that cannot be captured in the structured model efficiently enough, supplementary non-structured communication channels such as e-mail, video and telephone must always be provided.

- Different planning models and decision-making theories. The process depicted by the use cases is independent of the different prescriptive and descriptive planning processes that we have been discussing.

- Different phases of the mission. 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. The same entities of interaction may be used during all of these phases.

- Different command levels, services and activities. The differences between these different instances 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.

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.

In conclusion, the suggested generic model of C2 provides informative and precise input to the design process. Software tools derived from it have the potential to support C2 work throughout the entire military organization. The use of similar tools and methods will facilitate cooperation between the different positions, and thus greatly increase the effect of introducing a network.

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