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The Future of C2

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Agile Networking in Command and Control

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Abstract

Agile networked command and control (C2) should lead to a flexible and responsive force that can better deal with a highly uncertain, dynamic chain of operational events. Four essential elements of networked C2 are described, each with network characteristics of their own: cause-and-effect networks, social networks, information networks, and ICT networks. These form the basis for the development of agile C2.

Introduction

Much has been written about the new challenges of current and future missions. The main characteristics mentioned are the increased complexity due to the number of parties involved, the interrelated stakes, and the highly uncertain, dynamic chain of operational events requiring quick shifts between levels of humanitarian, peace keeping, and combat operations. Today's missions are always performed with military coalitions consisting of more and less advanced coalition members who need to cooperate and utilize each members' capabilities in the best possible ways aiming at synergy in the achievement of intended effects. Also, close cooperation with non-military organizations is required to reach the best possible effects in both the short and long term.

In order to cope with today's and tomorrow's mission challenges, it is important to understand these challenges and to develop new, more adequate concepts of operations and command and control approaches. Agility seems to be the Holy Grail that everybody is seeking. With increased agility, it is assumed that a coalition will be better able to apply the force elements and C2 approach that are most suitable to deal with a certain situation and that will support both the short- and long-term goals of all the contributing elements. It will also enable a coalition to move quickly to other approaches when changes in the environment require doing so.

Agile C2, which is the focus of this paper, refers to the capability of a force to adjust to and manage changing operational conditions. Agility is seen as including robustness, resilience, responsiveness, flexibility, innovation, and adaptation in order to be effective (Alberts and Hayes 2003). To achieve this requires a break with industrial age military paradigms, where the military coalition had to deal with massive, heavily armored army-sized opponents. New paradigms are required that are better capable in the new mission space, which is characterized by lightly armored, less identifiable, less traceable opponents often within civilian populations (Alberts and Hayes 2003). Matching and surpassing the agility of the opponent is a critical requirement, although the duration and lethal commitment that adversaries maintain is difficult to match (Van Creveld 2006). In order to achieve agility, it is required to have almost instant information sharing using robust networks, "self-organizing" social structures for high responsiveness and fast feedback, and understanding of cause-and-effect relationships.

Investments are currently high in robust technical networks that enable the contributing elements of a coalition to share information within their organization and between organizations within the coalition. Although a necessary requirement and hard enough in itself, this technical network or ICT (information and communications technology) infrastructure is only the starting point. Information management, social networks, and a good understanding of the nonlinear cause-and-effect relations are other necessary requirements. Information management must ensure that everyone has access to all the available information that is needed, at the right time and place, without much effort on one hand, but without being overwhelmed on the other hand.

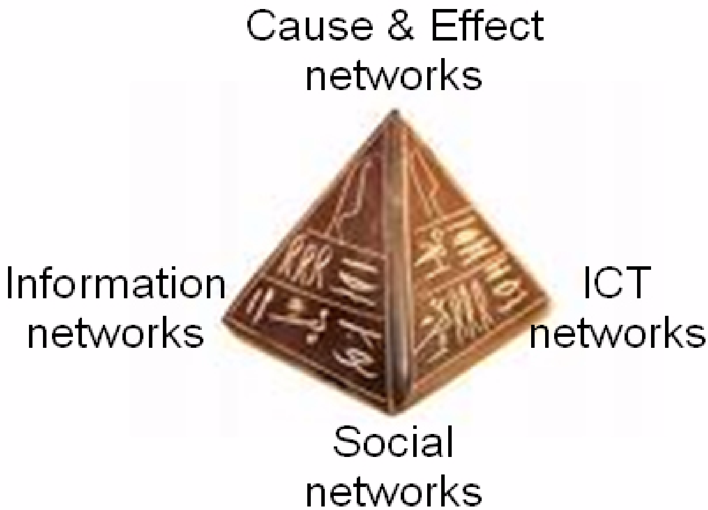

Figure 1. Four parallel operating networks coupled, each with own emerging behaviors generating agile C2.

In a networked environment, collaboration and sensemaking are no longer driven by hierarchical relationships of standing organizations but can be realized in social networks, at the right time with the right people. The collaborating elements may be formed ad hoc just before or even during the mission and quite often will not be co-located. This setting of collaboration requires well-developed cognitive, social, and cultural capabilities. Understanding the causes and effects in an operational environment where many parties are involved asks for a different look at the world. The complex nature of the mission space requires a break from traditional linear thinking and planned synchronization. We identified the above mentioned four elements to act as networks each on their own, but loosely coupled with each other. The concept of a network reflects the importance of the relationships that entities create with other entities. The activities of each entity will affect the other linked entities, which will result in dynamic, emerging network behavior.

Cause-and-Effects Networks[1]

Current military operations have to deal with a continuum of varying "conflict stages," ranging from peace, crisis response, major combat, and post-conflict. The boundaries between those stages are often vague and hostilities can take place in all stages. The reality is that military forces spend most of their time in non-combat stages. Instead of a sequence of several military actions that are well defined in time and scope, a campaign of actions may last for years and consist of a multitude of diverse, interrelated, and coordinated activities that are aimed at affecting all kinds of actors in the physical, economical, and psychological dimensions.

Today's missions are far more complex compared to traditional warfare. The desired effects, the actions needed to accomplish those effects, the effectors, and the groups at which the effects are aimed have expanded dramatically. They are also characterized by many, often unknown, unpredictable, or not understood interrelations where the behavior of the whole cannot simply be deduced from the behavior of individual components. The actions are aimed at armed groups, governmental, security, and civil organizations, and the prevailing living conditions of civilians. The effectors are not limited to the military arena. Diplomatic, information, military, civil, and economic actors should coordinate their actions to achieve their intended effects. The contributing nations should not only coordinate their efforts among themselves and among the different ministerial departments, but also with the local government, security forces, and societal organizations, all Non-Governmental Organizations (NGOs) and International Organizations (IOs), and neighboring countries that influence the area of operation as well.

1. Information provided by Belinda Smeenk M.Sc. (Belinda.Smeenk@tno.nl).

The complexity described above is in many respects about a large number of interrelated variables that are shaped by today's and yesterday's actions. Therefore, it has become quite difficult to understand the influence of our own actions on the operational environment. For planning purposes, it would be nice to know what actions will create the highest output. However, in this complex system of interrelated actors, actions, and desired effects, relationships between cause and effect are hard to determine or to measure, let alone to predict. The complete system changes continuously in response to many small and large activities.

In order to command and control complex military operations, NATO has defined the Effects Based Approach to Operations (EBAO). An EBAO promotes planning actions based on the effects the operation needs to achieve in order to arrive at the objective end state, rather than short-term military imperatives. Once the EBAO concept has been fully developed and applied, it should allow a better understanding of the interdependence of the effects generated by different actors facilitating enhanced coordination, cooperation, and coherence. One corollary is that it should also reduce the generation of unintended effects, which could ultimately hamper achieving the objectives and requirements of the end state. In this approach, the key for success is the coherent and comprehensive application of the various instruments and cooperation with all involved non-NATO actors in order to create the effects. Several nations are developing comparable EBAO conceptual frameworks, which are similar but differ on specific definitions. In current operations, nations are experimenting with the implementation of the EBAO concept. It starts with defining the effects instead of decision points (which is the approach in the current NATO operational planning guidelines) and interlinking the effects. These effects can then be translated into all sorts of tasks that can be carried out by different military, diplomatic, or civil actors at several levels.

In complex situations, the intended effects can only be achieved by an orchestrated deployment of military and non-military instruments. A number of capabilities are required to accomplish this.

First, a coalition consisting of military and non-military organizations must be able to develop a coherent set of plans based on the desired effects, the priorities among them, and mutual coordination. The set of plans should form an integrated whole that cuts across organizational, horizontal, and vertical boundaries. Second, it should be possible to coordinate the activities initiated from these plans. Again, the coordination should not be hindered by the above mentioned boundaries. Instead, the progress of actions should be transparent across organizations, horizontal units, and hierarchical levels. Third, the set of plans at all levels should be adjusted continuously to take into account the progress of all actions and the changes in the complex environment. Current operational decision processes are not well equipped to support this. Planning and execution are still strictly separated and different planning and planning-adjustment processes and methods are applied. Last, plans with the traditional development of three Courses of Actions are not adequate anymore. In today's operations, a much wider range of options is available and different methods are needed to support the selection from among the potentially effective options and sets of options. Selecting appropriate options requires good operational information and intelligence and a networked and collaborative environment to share it.

To get insight into the cause-and-effect relationships and to support the implementation of the above mentioned requirements, several nations have expanded their planning staffs with operational analysts. The Netherlands supplied analysts from TNO Defence, Security and Safety to the Dutch staff and units in Afghanistan (Smeenk 2007). The first challenge for the analysts was to define measurable indicators for all foreseeable effects (Measures of Effectiveness) and for the tasks necessary to reach those effects (Measures of Performance). Their second challenge was to collect data for these indicators. As input for the measurements, they used the data from the intelligence section, but also all other types of reporting that might contain relevant information. Since most intended effects are not physical but psychological, it is harder to collect quantitative data. A practical solution is the use of psychological research methods and expert judgment of the results obtained. For instance, winning the hearts and minds of the population and influencing their behavior is one of the important outcome measures of interest. The measurement and quality of data might be improved by using local polling agencies, which would avoid the connotation of a military purpose. Although it should be easy to quantify one's own tasks, in practice we have found that operational units do not report performance or outcome-related statistics for their tasks. In order to relate our own tasks to effects, more detailed insight is needed into the frequency and geographical coverage of tasks. If more data were in place, it might then be possible to model and analyze cause-and-effect relationships with methods such as the *Method to Analyse Relations between Variables using Enriched Loops* (MARVEL) (Zijderveld 2007).

Since all units in a mission contribute to the establishment of situational awareness of the operational environment, it is important that they receive relevant and up-to-date information on the current situation, the history of their own activities, the intended effect (aim), and the required missing information, for instance, regarding a specific village where they will conduct their tasks. Such operations can be discussed if all units understand the complexity of the operational environment and the complete list of the intended effects. It is probably acceptable for the task executors to know what the aim is in a specific village; however, it is desirable that they understand what information might be relevant for higher echelons or decision-makers. This can be enhanced by giving them clear guidance on the information requirements of the higher echelons.

The effect based approach in Afghanistan has led to a positive change in the mindset of the planners. However, it is clear that much is still to be done to create an optimal, integrated effective approach. Improvements at all levels of networking—organizational, informational, and ICT networking—are necessary.

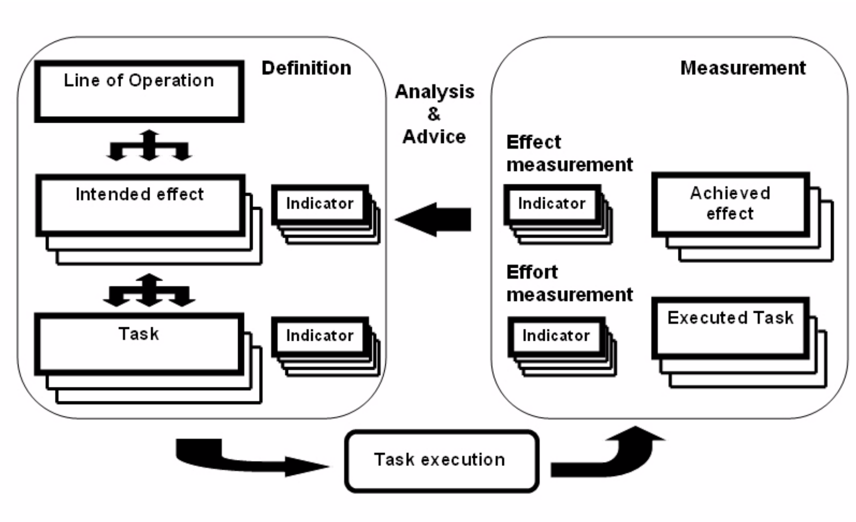

Figure 2. Effects definition and measurement as part of the EBAO-approach implemented by the TNO operational analysts as part of the staff of Task Force Uruzgan.

Social Networks

In general, people work in organized social arrangements, such as in sections, units, departments, projects, and teams. Besides the formally organized linkages, people have many other connections to other people in the organization and outside it. Both formal and informal linkages between people form the social networks that provide the basis for the behaviors of an organization. Richly linked people and clusters of people are better able to develop shared situation awareness, solve unusual problems, synchronize activities, and develop trust without centralized control. New organizational concepts, such as the networked approach, are being developed to exploit the powers of social networks. However, according to a recent review, there is a huge gap between what we need to know about networks and the primitive state of our fundamental knowledge to ensure the smooth working of networked C2 (National Research Council 2006). Still, we think that the realization of effective social networks is critical for the realization of agile networking;

therefore it requires focal attention in C2 research. Three critical issues for the realization of social networks in agile C2 should be raised here. With the creation of ad hoc coalitions and the system of rotations, social networks are difficult to mature in a timely way. Also, the geographical distribution of interdependent parties creates additional obstacles even in single service organizations. Finally, cultural differences further complicate the development of effective networks for existing forms as well as for new organizational forms. In a recent study on the competencies of future commanders, operational commanders considered the difficulties of building trust, cohesion, and partnerships with distributed parties as major obstacles to effective command (Van Bemmel and Le Grand 2006). How can we address these problems and transform them into innovations? These issues are being studied in several directions, which will be discussed below. One direction is the study of distributed command teams, where a virtual staff, or staff capacity, is formed from distributed staff elements and specialists somewhere in the network. A second direction is a drastic deviation from traditional headquarters with their large staffs. The concept is to fix a small high level decision-making team of commanders to one place, the "operational cockpit," where they reach decisions with each other, and in parallel can lead their organization using direct interactions and communication media.

Adaptive Distributed Command Teams (ADCT) [2]

Developments in Information and Communication Technology enable organizational flexibility. Coherent collaboration among distributed units becomes easier (virtual teaming). Proximity is not a condition for real-time collaboration anymore. Networked environments make it possible to connect people at any time and any place in an ad hoc manner. One of the advantages is that staffs or teams can be tailor-made and tuned to specific missions or situations. People with specific expertise and experience can be added to a com-

2. Information provided by Jouke Rypkema (Jouk.Rypkema@tno.nl).

mand team when needed for the mission. Command and control can thus become less dependent on the available capabilities of a staff at a certain location.

Distributed ad hoc teaming has also disadvantages. For example, in traditional staffs, members train together and are aware of each others' skills, expertise, tasks, and responsibilities. This knowledge makes it easy to identify the most appropriate member to perform a specific task. In an ad hoc team, even when co-located, it might not be immediately clear which person can do the job. It takes more effort to find the right team members. Similarly, people who are part of a traditional staff know what the current situation is and what staff processes are in progress. Newly added members are not always aware of these concerns and have to be briefed explicitly on these issues.

Besides the difficulty of not having a common background or sufficient familiarity with each other, communication processes that are natural and easily established for co-located teams are seriously distorted during distance collaboration. For example, people might hesitate to use electronic communication tools because they appear to require too much effort. Consequently, communication becomes less frequent, leading to a lower level of information exchange (Eikelboom, van der Lee, and Rypkema 2006). Also, non-verbal communication is virtually absent, which means that non-verbal messages are not received (Kiesler and Cummings 2002). Informal communication is limited, although informal communication has proven to be critical for sharing and synchronizing ideas (Kraut, Fussell, Brennan, and Siegel 2002). This greatly reduced level of communication and reduced quality of interaction has negative effects on the sharing of intent, sensemaking processes, shared understanding, and trust, potentially leading to decreased mission effectiveness.

In order to make distributed command teams work effectively and adapt to the dynamics of the environment, alternative work processes and support tools are needed to enable the tasked group of people to develop into a team and maintain team cohesion and effectiveness. These work processes should be set up such that team members can easily share each others' expertise and experience, maintain awareness of the activities of other team members, share vision, and provide feedback to each other. Limitations in communication should be compensated for using tools that enable accessible, frequent verbal and non-verbal communication. The working environment, processes, and tools should provide many opportunities for interactions and informal communications between team members. In fact, this approach should also help to develop and maintain the larger social network of other individuals, groups, and teams.

The drawbacks of distributed collaborative work raise the question of whether it can be applied effectively and in which missions it can be or should be applied. If co-location costs are high, the safety of a high concentration of people is a significant concern, and diverse experts are needed, then distributed collaborative work is an option or may even become a requirement. On the other hand, if problem solving and ethical deliberations—which require intensive interaction between the parties involved—are the major part of the work, then co-location is preferred. Research is underway to find out how well these activities may be executed in distributed setups and what support might be effective. This research aims at organizational and procedural concepts and criteria to aid decisionmakers in choosing whether or not to apply distributed teaming.

The Role of HQs in Agile Networking[3]

Strategic planning and control of international operations is usually accommodated in permanent joint headquarters (PJHQ). The PJHQ is the linchpin between the political and the military level. The link to the military level is established by the communication of the PJHQ to the deployed Joint Forces Command Headquarters

3. Information provided by Dr. Peter Rasker (Peter.Rasker@tno.nl).

and/or the regional commands. Politicians will determine the boundaries within which international operations must be carried out. The PJHQ's main tasks are to plan, overlook, and monitor the international operations so that the boundaries are not crossed, and to provide the politicians with strategic military advice.

Although the PJHQ often has a good technical infrastructure, unlike the deployed headquarters, they are faced with challenges in another dimension. Being the link between the political and military arenas brings particular requirements that impact the flexible and rapid functioning of the PJHQ. Being responsible for planning and monitoring of large international operations, the PJHQ is regularly confronted with quite diverse political demands, such as ad hoc requests for military cargo aircraft or Special Forces. Usually these higher level requests must be answered and fulfilled immediately. Politicians may also have detailed questions, often media driven, concerning the ongoing operations. These must also be answered at once. As a consequence, a PJHQ's workload is strongly affected by the unpredictable and ad hoc needs of the political system, which interferes or even disrupt the regular, time-intensive planning and monitoring of military operations. Moreover, the high need at the political level for detailed information about the ongoing operations leads to information overload and creates a tendency to micromanage. Especially during incidents and crises, time is often too short for an extensive pursuit of information and expertise in order to formulate answers and advice for the political level. This description of the dynamics of a PJHQ shows that while the dynamics of the operational field and the agility of the adversaries require an agile organization, the "internal" political-military dynamics can also be high and require flexible, adaptive organizational structures and flexible people and working environments.

To address these issues and improve the agility of the PJHQ, a new command and control concept and related support environment was designed (code name "Cannibal Hector"[4]; see Figure 3). The concept is that only a small team of high level decisionmakers is operational, works together to solve problems, and has direct connections with the other levels of command, including the lower (and lowest) command levels. This will enable them to quickly switch between levels of command and the related operational details.

Figure 3. The new command environment ("Cannibal Hector") to support a networked operational command concept.

The most promising feature is that the commanders' individual work and their team work can be performed concurrently while being connected to their distributed colleagues and lower commanders. These parallel work processes should assist commanders in the PJHQ in making fast and qualitatively good decisions. Especially during incidents and crises, this might enable the PJHQ to formulate rapid, high quality answers and advice suited to political needs. Where the study of distributed command teams (ADCT, discussed above) takes existing structures and develops those into new operationally supported settings, this concept takes maximum advantage of distributed work in a networked environment and takes a larger step into a future of operational and stra-

4. The name "Cannibal Hector" refers freely to the extreme reduced manning of operational command while producing highly effective command power with its focus on the humans in command.

tegic decision-making with minimal manning, with direct links to all command levels. Research is ongoing to discover the adequate behaviors and resolve or manage the potential traps of this command concept. One potential trap most often mentioned is micromanagement. After all, detailed information becomes directly available at higher levels. We believe the availability of detailed information is critical to support timely and quality decision-making, and it is possible to avoid micromanagement through good management of command focus.

Shared Awareness and Understanding[5]

One of the main reasons to foster social networks is the operational power of having shared awareness, a shared understanding of what the current situation is, a shared sense of what the operational implications are, and a shared intent about the direction of the mission. Awareness does not exist in the information system but in the human mind. People naturally combine information with their expectations from prior experience and mental models, including cause-and-effect relationships, and develop them into meaningful stories by filling in the blanks. Shared awareness can exist in the individuals' heads if each person has the same interpretation of the situation. One problem is that people have different perceptions and backgrounds. People interpret available information in different ways, and therefore see different things in the same operational picture. The current NEC development heavily on realizing a joint common operational picture (COP), driven by information and ICT networks. Currently, the objective COP boils down to combining maritime, air, and land recognized pictures into one interoperable system. This coherent and up-to-date joint operational picture is expected to drive shared awareness and understanding and thus enable more effective command and control. Differences in interpretations are caused by operator experience and training (Randel, Lauren Pugh, and Reed 1996), but for future combined and joint

5. Information provided by Dr. Guido te Brake (Guido.Tebrake@tno.nl).

operations, cultural differences are important as well (Klein, Pongonis, and Klein 2000). Hence, a shared understanding of the situation, the possibilities, and the threats is not a natural direct result of sharing information. A joint COP is required for obtaining shared awareness (see detailed discussion below), but it is not sufficient. The following dimensions should be considered when shared awareness is desired:

- Situational awareness (SA). SA is the perception and comprehension of entities in the environment, and the meaning they have for your mission.
- Team awareness (TA). TA is the understanding of the status of our own entities, a concept also referred to as self awareness or organizational awareness. Where are my partners and subordinates? What are they doing? How are they doing? Which capabilities are available?
- Intent awareness (IA). IA is the understanding people in the organization have of the command intent and the implications it has for their tasks. This is especially important in distributed networked organizations where responsibilities are given to lower echelons and self-synchronization becomes more important (Alberts and Hayes 2003).

It is important to realize that shared awareness is not a goal in itself, but is required for synchronized and effective decision-making, especially in distributed settings. It is not necessary that people have all the available information all the time, because this guarantees information overload. The amount and type of shared awareness necessary for effective operations depend on the organization, doctrine, mission, rules of engagement, and probably several other factors. Research should provide knowledge about the relationships between situational factors and the information, knowledge, and awareness that must be shared, and how the development of shared awareness can be supported.

Information Networks

In support of the interactions in the social network discussed above, an *information network* exists. Logically, the nodes of this network represent perceptions of (abstract or concrete) real-world concepts while the edges represent relationships among the nodes. Both nodes and edges can have attributes. Philosophically, the information network exists regardless of whether or not there is a concrete representation. It is obvious, however, that a concrete representation of the information network is indispensable in complex military operations. This explicit representation typically resides in various information systems and databases.

The information network is an expression of the operational situation. It creates the ability to share information between different elements. Newly discovered nodes and relationships can be added, and (attributes of) existing nodes and relationships can be modified. The main challenge in the information network is to ensure that the *right* information is available at the *right* time in the *right* format to the *right* person for the *right* use, without causing information overload. This general information management challenge is even more challenging in military operations. First, in military operations the explicit representation of the information network is distributed by nature, while the underlying infrastructure is not always as available or performing as desired. Second, and more fundamental, relationships between nodes are not always explicitly represented, although these relationships are essential for efficient navigation through the network. To a large extent, information overload is caused by the fact that lots of information must be conveyed through networks and analyzed because of the poorly structured nature of the information; i.e., because meaningful nodes and relations are still to be discovered.

This discussion of the information network shows that it has to be agile because it must be able to follow the dynamics of the social network. Furthermore, the information network is agile because the contents of the network (nodes as well as relationships) are context dependent and must be discovered dynamically. The sections on *Common Operational Picture* and *Interoperability* discuss the implications of social network agility. In the section on *Enrichment of the COP*, content-agility is elaborated upon.

Common Operational Picture[6]

A Common Operational Picture contributes to both the individual and shared situational awareness of the participants within a force and can be seen as a situation dependent and often dynamic segment of the information network. Given the need for agility, implied by the agility of the social network (varying set of participants and interaction patterns) as well as the agility inherent to the information network (varying information needs dependent on the tasks and needs of the users), the contents of a COP will also vary for different groups of users and within different missions or within phases of a mission. The numerous occurrences of the term *COP*, all of them with (somewhat) different content, within current operations, exercises, and demonstrations, illustrate this. The abovementioned five *rights* of information management (right information, right time, etc.) also stress the importance of tailoring the information provision to the user's needs.

Keeping these observations in mind, there is a need to find a definition and an approach to realize COPs that are flexible in their information content on the one hand and that still have a common basis on the other hand. We suggest connecting the notion of the COP to the notion of the Community of Interest as follows:

- A COP is scoped for a certain Community of Interest (COI) that performs one or more military functions and/or cooperates within a certain operation/scenario. Note that a COI is not defined in terms of composing operational units, because, as

6.Information provided by Marcel van Hekken M.Sc. (Marcel.Vanhekken@tno.nl).

stated in the introduction, the set of participating operational units must be flexible. The approach of deriving information needs per COI is taken in the development of the Bi-SC AIS system as well (NATO NC3A 2005).

- A COP may contain all of the following main information items, being a mix of (geo)graphical and alphanumerical information:
    - Current situation, both internal and external factors (of influence)
    - Command intent
    - Planning of activities in time and actors involved
    - Progress/completion of activities

These main information items are decomposed further into a standard set of *information areas*.

- Within a COI, a COP may have various representations for different players, dependent on their specific information needs and on the physical circumstances in which their operations take place (*personalized COP*).
- Information that is relevant for more than one COI (and so is part of more than one COP) is mutually synchronized, based on a *commonly available information base*.

As a consequence of the approach described above, the "C" of the term COP does not mean that everyone receives the same information. Nor does the "O" mean that a COP is limited to the operational level, or the "P" that a COP is only a (graphical) picture.

We suggest the following global approach to start the realization of the COI-related COPs as mentioned above:

- Identify COIs at a reasonable level of granularity. This is by no means trivial. The guidelines for deriving Information Interoperability Domain provided by Lasschuyt (2003; 2004) might be of use here.

- Determine which currently existing operational units could be part of which COI.
- Define the specific information needs (COP requirements) for each operational unit within a COI, in terms of information areas and the characteristics of them (timeliness, accuracy, update rate, reliability, push/pull, representation).
- Assess the available (ICT) means to meet the specific information needs for each operational unit within a COI.
- Analyze gaps and bottlenecks by comparing the information needs with the (ICT) means to meet them. The results of this analysis could be the starting point for implementation efforts.

Enrichment of the COP[7]

During the past couple of years, most Western military nations invested in communication and information systems that support Shared Situation Awareness at all military levels. These typically COP-like systems offer their military users information about the current situation and future plans. This information consists of facts that were observed or determined by others and characteristics of future actions that will be performed.

It must be noted that information offered by these systems is not the same as situation awareness (SA). SA is an attribute of an individual's consciousness. Situation understanding (SU) is one level beyond SA and deals with the understanding of what is going on, what the intentions of all relevant parties are, how these parties will most likely act to implement these intentions and what is possible and what should be done to implement one's own intentions.

When a commander or staff member (a decision maker) deduces SA and SU from information offered by their systems, they will go through a mental process that combines this information with their existing knowledge, which continuously updates their mental model

7. Information provided by Henk Jansen M.Sc. (Henk.Jansen1@tno.nl).

of the situation. As such they will enrich this information, search for more details, recognize patterns, relationships, higher level abstractions, and aggregations, etc. This is not a linear process but instead consists of continuous iterations that will result in implicit intermediary products (awareness or understanding that is not yet rich enough for the purpose).

During this mental process, the decision maker will regularly verbally with other decision makers to verify their judgments and conclusions, to complete and enrich their awareness and understanding, and to make certain that the other decision makers have the same SA and SU. However, decision makers will not always be in close proximity to each other. This is already true in current operations, but will most likely be the case in a mature networked organization. Nevertheless, decision makers would like to benefit from each others' thought products, not only for their end products, but also for their intermediary products. If we assume the networks and the information systems are available, it makes sense to look at ways to enhance the richness of information in the current systems in such a way that it will enable their users to digitally share their awareness and understanding and benefit from others' awareness and understanding. To express it in the terms we used in the introductory section of the information network part of this paper: the higher level abstractions and aggregations must be added as nodes and relations in the information network, representing higher level concepts.

With this in mind, TNO performs research to enrich the current information models. For this purpose, information management, command and control, and human factor experts are working closely together. The approach taken is to look at the process a decision maker goes through, which starts with the intention and the recorded facts of the situation. A first flavor of the approach is documented in (Treurniet 1998). Our assumption is that during this process, the decision maker will consider groups of objects (as part of the recorded facts) and assign meaning to this group. Objects can be anything from vehicles to terrain features or more abstract features like functional behaviors and capabilities. The meaning can be expressed as a relationship between the objects with certain characteristics. For instance, "this particular group of objects might constitute the air defense of the enemy, which is able to cover a certain area" or "this area is not passable for our troops."

We are experimenting with the principles of the semantic web in order to record the intermediate products of the decision makers. The semantic web principles will enable the decision makers to record all kind of relationships and new objects without a restriction to a certain type of relationship. The challenge will be to provide the decision makers with a tool that is able to follow their mental process without influencing their speed of thinking too much. Of course it is inevitable to have some influence. However, the benefit will be in the time it takes to interact with other decision makers that are part of the overall process. If the combined result of all decision makers in the process is positive, it is worth the trouble to support this process with the suggested tools.

Interoperability[8]

Achieving and enriching a COP implies broad sharing of information among the many parties involved in a military operation. This requires a network of information providers and consumers allowing for a seamless exchange of information. Since much (structured) information is kept in separate, often heterogeneous (C2) information systems, a high level of interoperability between these systems is needed. However, currently there is still a severe lack of interoperability between most systems, which causes commanders to receive insufficient or outdated information from their coalition partners. Although many individual systems work well, the transfer of information between them is often not operationally viable. Despite today's advanced information technology, sharing information is still difficult. One of the key problems is the lack of common repre-

8. Information provided by Eddie Lasschuyt M.Sc. (Eddie.Lasschuyt@tno.nl).

sentation of data, which is needed for true understanding of information by people and processing by machines, especially across national boundaries. Another major issue is the need for a scalable and flexible interoperability solution that enables coalition-wide information exchange, i.e., for all operational components at all command levels supporting any functional area.

Interoperability between heterogeneous systems in large environments is usually best achieved by defining a common information standard. It homogenizes the meaning of the data and prescribes a general data structure and format to be used when data is exchanged. The standard is often specified by means of a data model, called an "Information Exchange Data Model" (IEDM). Currently, Multi-lateral Interoperability Programme (MIP) is the major program in a coalition context that develops such an IEDM, in cooperation with NATO Data Adminstration Group (NDAG). The model is named the "Joint Consultation, Command & Control IEDM" (JC3IEDM). Within its (potential) scope is all C3 information that may be shared in support of any joint and combined operation. Each Information Exchange Requirement (IER) submitted to MIP is basically added to the JC3IEDM. In a broader context, given the need for coalition-wide interoperability—also outside the C3 area (e.g., Intel and Logistics)—working towards a single IEDM may present significant problems. Such a large IEDM would be very complex and thus hard to develop, maintain, and use. Also, development would slow down considerably due to the many interested parties that would be involved. A somewhat different, non-monolithic approach may be required.

Such an approach was designed by TNO (Lasschuyt 2003; Lasschuyt 2004). It advocates the use of multiple IEDMs to enable interoperability in large environments. The so-called "domain-based approach to IEDM development" divides an information area into more or less independent "Information Interoperability Domains," collections of information systems that interact via a specific IEDM. Expectedly, a single domain (IEDM) for the entire NATO information exchange area is unlikely to ever achieved.

Therefore multiple domains are inevitable, each using its own IEDM. This means that the NATO information area will have to be divided into a number of domains, each having its own IEDM to describe the data common within that domain. Some potential domains are Logistics, Intelligence, Joint C2, Land C2, CBRN, etc. The IEDMs must be clearly scoped and their overlap must be minimized. In order to enable information exchange between systems out of different domains, the IEDMs are related to each other (in a "domain structure") and harmonized (using a common model basis). Domain scopes, structure, and basis are defined centrally. Within these margins, specific Communities of Interest can be made responsible for developing their own IEDM independently. Only some degree of harmonization between these activities by a central (NATO) body is needed. In general, the domain-based approach enables separate information standardization efforts to be related, working towards a structure of standards that together provide overall interoperability. The approach offers a practical way of organizing the development of information exchange standards on a large scale. Although the emphasis here is laid on IEDMs (data models), the domain-based approach also works with other data representations (e.g., ontologies). The approach, including the intended roles for NATO and the COIs, differs from the current way of working, though migration in this direction is seen as realistic.

In general, broad information interoperability among coalition systems, also outside the boundaries of COIs, is thought easier to achieve when a domain-based approach is applied. By creating multiple, yet related IEDMs, the overall information standardization process will become more efficient and manageable than in the case of working towards a single all-encompassing IEDM. When IEDMs are more closely related to the functional area of COIs, this will ease their development. It also enables parallel development of information standards, which can lead to NATO-wide interoperability sooner. In addition, the IEDMs—being smaller and less complex—will be easier to create, comprehend, maintain, and implement, and will be more flexible in terms of change management. Yet, the resulting IEDMs would facilitate the same global (inter-COI) interoperability as an (imaginary) super-IEDM would do. The approach seems to be a promising way to go.

Since 2001, the domain-based approach has been a subject within the NATO Information Systems Technology panel (NATO/RTO/IST).[9] An IST Exploratory Team investigated the viability of the domain-based approach in 2006. Based upon expert opinions (from MIP and NDAG), the team concluded that the approach seems technically sound, although a proof-of-concept is still needed. The approach could be very useful in dealing with the increasing pile of IERs waiting to be handled by MIP for inclusion in the JC3IEDM. Dividing these IERs among several COIs to create their own IEDM, under coordination by NDAG, could speed up the overall standardization process in NATO. A number of challenges were also recognized, especially regarding the organizational and procedural aspects, the few available COIs that presently possess (or work on) an IEDM for their functional area and the lack of mandate to control IEDM developments within NATO. Still, the advantages of the approach seem to be quite obvious. If enough nations and COIs can be convinced of that and if they are willing to cooperate, it may very well work. The team therefore concluded it would be worthwhile to set up an experiment, in a follow-on IST Task Group, hereby focusing on the technical and methodical aspects of the domain-based approach. A proof-of-concept must give more insight in the efficiency of the IEDM development process, the applicability of multiple IEDMs to support data exchange between systems and the technical compatibility with existing and emerging technologies for data exchange. The proposed group has to assess whether the approach and its expected benefits are realistic.

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9. See for description of IST and other technological panels: http://www.rta.nato.int/.

Smart ICT Network of Networks[10]

The ICT infrastructure is the layer of the information architecture that provides services for interactions and the exchange of data. These services can be used by humans or information systems or by combinations of both. Given the important roles of interaction and information exchange, the criticality of the ICT infrastructure is higher than ever before. The agility of the ICT infrastructure must be very high as well: first, to reflect the agility of the social network and the information network, but second, to cope with physical and environmental limitations. Particularly under mobile circumstances, these limitations hamper communications severely. Ideally, each of the operational nodes (varying from a dismounted soldier or even an unmanned entity or disposable sensor up to a static headquarters) must dynamically provided with interaction and exchange services that strike an optimal balance between actual needs and actual possibilities. This section discusses three promising mechanisms to give shape to this agility.

Information Application Adaptation by End-to-End Quality of Service (QoS) in Hastily Formed ICT Networks

The ICT network of networks in the near future is generally composed of different interconnected (legacy) networks from a coalition of forces. In some cases, for example in crisis response situations, the network of networks may even be called *hastily formed*. These heterogeneous networks, wired as well as wireless, need a built-in management structure that does not require knowledge of the overall network topology. Instead at the request of a local application, the network management structure needs certain knowledge and intelligence locally. First, it needs the knowledge of the local demands for information distribution over the network; second, it needs the knowledge of the locally available communication performance (or more generally the quality of service); and, last but not least, it needs

10. Information provided by Cor van Waveren M.Sc. (Cor.vanWaveren@tno.nl).

embedded dynamic intelligence in the network to make the best combination of applications and communication systems and routing chain through the networks. With this awareness, the chain can be optimized and congestion in the ICT networks can be prevented in an emergent way. Optimization by adaptation of the command and control application, as a result of the knowledge that a communication link in the chain has limited capacity, can be achieved, for example, by using gracefully degraded command and control applications with reduced performance or prioritizing demands for information distribution over the network.

Disruption-tolerance

Wireless communication networks suffer from transmission impairments. Especially under mobile circumstances in a tactical environment, it shows a disruptive nature with frequency-dependent availability. Given this nature, wireless mobile networks should be flexible and agile to adapt and optimize the transmission waveforms for the specific mobile propagation circumstances and to reduce or avoid disruptions. Software Defined Radio technology is vitally important to achieving this functionality. For example, by using the ad hoc routing concept in a network, disruptions can be avoided and the network performance can be improved.

Spectrally Adaptive Wireless Networks

The scarcity of radio spectrum is a limiting factor in large-scale usage of wireless (broadband) data communication. In spite of the scarcity of radio spectrum, it is generally accepted that the spectrum occupancy by licensed spectrum users is very low and often radio spectrum is unused.

Adaptive, spectrum-agile and cognitive wireless networks have the potential to utilize the large amount of unused spectrum in an intelligent way while not interfering with other incumbently licensed spectrum users. In 2006, DARPA (Defense Advanced Research Projects Agency) succeeded in Spectrally Adaptive Radio experiments. This mechanism[11] has the potential to unleash tremendous spectrum capacity. Agile networking, with the ability to occupy unused radio spectrum, will therefore contribute substantially to efficient spectrum utilization and proportionately more available communication capacity.

The above mentioned promising mechanisms are subjects in TNO research programs. For example, in the project "Innovative Information Infrastructure Concepts" for the Dutch Army, a vision is being developed on ICT infrastructure concepts for the future military communication networks in the Deployed and Mobile Domain of the Royal Netherlands Army, with the objective of diminishing the gap between the desired robust ICT infrastructure and the current ICT infrastructure, in a gradual way and in accordance with the NEC ideas. In addition, TNO is also participating in Research Framework Programmes of the European Committee and the European Defence Agency (EDA) on SDR, CR, and WMN (Wireless Mesh Networks). Each of these concepts has its own distinguished features that can contribute to the development of adaptive and agile networks.

Complex Adaptive Systems[12]

In the preceding paragraphs, military command and control has been viewed from four perspectives, represented by distinguishable but strongly related networks. The characteristics, the dynamic behavior, and the complexity of these networks give good reasons to consider each of these networks as a Complex Adaptive System (CAS). This viewpoint results in new insights that are necessary to deal with the required agility of these systems. As a matter of fact, all

11. This mechanism is based on the emerging technology of "Cognitive Radio."
12. Information provided by Anthonie van Lieburg (Anthonie.vanLieburg@tno.nl).

mentioned networks—some of which are internal, external, or both—can be considered CAS as well as the combination of them, which forms a CAS system of systems.

Before describing what a CAS is, it is important to mention that in the past similar systems also exhibited complex, dynamic, and non-linear behavior and therefore could also have been considered CAS. What has changed is the fact that in traditional warfare, you could suffice with linear thinking. Effects were very often limited to aspects of warfare that mainly dealt with linear and well-understood concepts. Other concepts were ignored and in most cases did not seem to cause problems. In today's operations, ignoring those concepts or aspects of warfare would simply mean failure of the mission.

A CAS is a dynamic network of many agents which may represent intelligent systems, individuals, groups, and units acting in parallel, constantly acting and reacting to what the other agents are doing. The overall behavior of the system is the result of a huge number of decisions made every moment by many individual agents throughout the system. Adaptability of the system means that the behavior of the system changes over time as result of interaction and feedback on the increase of its success (Grisogono 2006).

This adaptability to change, to learn, gives a CAS its agility, which comprises flexibility as well as stability resulting in characteristics such as resilience (recovery from damage) and robustness to perturbations (maintaining the core functions). If however its adaptive capacity is exhausted, while looking unaffected by changes, it can suddenly enter into a completely different regime of unforeseen dynamics. The ability to explore new ways of increasing its effectiveness and/or efficiency can result in coevolution with the other evolving systems it is interacting with.

Although there are many things to be understood while dealing with CAS, three aspects are of special interest. These are emergence, nonlinearity, and adaptation. Emergence is the phenomena in which complex system behaviors "spontaneously" arise from simple interacting components. In these systems, it is the constitution of the system and its local interactions that determine the overall capabilities instead of the individual capabilities. This also means that simply monitoring high level dynamics does not necessary lead to insight into individual behaviors and vice versa. On the other hand, emergence may be utilized to enable large scale or novel changes just by applying some small changes to the constituents, rules, or interactions within an organization. When dealing with complex systems, emergence is an important aspect to consider, both from a success and failure perspective. Within human as well within natural and engineered complex systems, emergence can provide an interesting source for improvement or a devastating failure.

A second interesting aspect of complex systems is nonlinearity. Nonlinearity is closely associated with sudden, or more correctly unexpected, change, collapse, and chaos. This nonlinearity in complex systems is an important cause of their complex dynamics and when dealing with CAS-like systems prediction of its future behavior can be very hard or impossible. Due to this nonlinearity, a very stable and predictable looking complex system can transform into an unexpected structure just a minor change. And although in some cases close observation of their dynamics may reveal some trends, precise predictions are not the best starting points for planning strategies and approaches. Rather than a single focus on prediction of future events or behaviors, it will be worth looking at other strategies for coping with the unexpected.

Adaptation is the process in which a system "learns from experience," i.e., the results of interaction with its surrounding world, either successes or failures, are incorporated into the system thereby increasing its probability for future success. It will be clear that the more complex the environment around a system becomes, the more important is the ability to adapt. Adaptation is a fundamental property of natural CAS and can be found at many levels and in many forms. In the work of Grisogono [1] four essential components of an adaptive mechanism are identified: (1) a concept of "fitness" or relative success and failure, (2) a source of variation in some parts of the system, (3) a means of testing the variations produced for their impact on fitness, and (4) a selection process that retains successful variations. In most known complex adaptive systems these four mechanisms will be found. Explicit knowledge of these components can provide useful clues for improving an organization's or system's overall performance in terms of agility, resilience, responsive, and flexibility. On the other hand, the same kind of knowledge can be used to disrupt the process of adaptation in an organization or system, thereby decreasing its ability to be agile, flexible, responsive, or resilient. Typically such a process of disrupting adaptive capabilities can be employed before more conventional ways of distorting an organization or system.

Due to the complexity and dynamics of today's crisis situations and regional conflicts and due to the complexity of the coalitions dealing with them, the insights and viewpoints of Complex Adaptive Systems can help to understand the behavior and interactions of military and non-military organizations in those crises and conflicts. As such, this CAS approach can support modeling and simulation, operational analysis, training, and decision making, and can help to apply an appropriate command and control approach and an appropriate concept of operation in each situation.

To successfully apply CAS thinking into the Defense domain, much pioneering research is required. A thorough understanding of the nature of complex (adaptive) systems and their dynamics is required. Complexity science and its associated tools have begun to provide this knowledge and the methods for studying complex systems. The scientific disciplines that study their own typical complex systems (e.g., biologists study ecosystems, economists look at stock markets, social scientists study human culture) should be brought together, combining their experience and knowledge for successful application of CAS to the Defense domain. Besides understanding and close collaboration with other disciplines, the application of CAS could start with recognition and identification of complex (adaptive) systems' characteristics in our own and other organizations. For example, by identifying the informal feedback loops and their effects on organizational dynamics, adaptive mechanisms of the organization may be revealed that were not explicitly described before.

Conclusion

Today's missions require a different approach to C2 compared to traditional operations that were common in the past century. Instead of a "nice to have" characteristic, agility of forces and C2 has become crucial. Agility is the ability to maintain effectiveness in a dynamic, complex, and rapidly changing environment. Agility of a unit, an organization, or a coalition is the result of the capabilities of their elements and, even more importantly, the networked relationships between those elements. Within this context four essential networks can be distinguished that are relevant for C2:

- the cause-and-effect dynamics of the environment, in particular the understanding of the effects that actions and events have on the perceptions and behaviors of all parties involved
- the formal and informal communications and sensemaking interactions in the social network of the people in the organizations involved
- the dynamic development and creation of operational information representations, elementary and aggregated, from distributed information elements
- the adaptation of the information and communication infrastructures and services to the operational conditions

Agility is not something that can be implemented at once but instead develops through the capability of individuals and organizations to understand, detect, and learn the dynamics of the system, to communicate these understandings in rich interactions, to create, find, and use relevant information, and to support these processes with ad hoc infrastructures. Understanding the processes of these networks and their emerging behavioral properties is crucial for the development and improvement of agile C2 systems. A Complex Adaptive Systems approach might help to identify the underlying mechanisms of these networks. We believe that many small scale naturalistic experiments are needed to build the evidence base for the transformation toward agile C2. Experimentation takes time, but evidence will in the end accelerate the achievement of more effective C2. The studies on agile C2 described here reflect the efforts by TNO to bring experts from different domains together in a research network aimed at joint development and experimentation.

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