15th ICCRTS

"The Evolution of C2"

Mission Design: Fitting the Solution to the Problem

Track 1: C2 Concepts, Theory, and Policy

Eva Jensen

Department of Military Studies
Swedish National Defence College

Point of contact:
Eva Jensen
Department of Military Studies
Swedish National Defence College
P.O. Box 27805
SE-115 93 Stockholm
SWEDEN
Telephone: +46 8 55342610
Fax: +46 8 55342600
E-mail: eva.jensen@fhs.se

Mission Design: Fitting the Solution to the Problem

C2 systems and their products (plans and orders) are artifacts *designed* to solve problems. They should therefore be analyzed in accordance with the logic of design. An artifact is designed for a purpose, and has to fulfill a set of necessary functions in order to achieve the purpose. The artifact is put to use in some context where there are problems to solve (the outer system). Problem solution depends on how well the artifact together with its user(s), i.e. the inner system, interfaces with the outer system. Most existing theories of C2 focus on the inner system. The present study builds on the work by Brehmer, who includes the outer system in his theory of C2, in combination with the method of cognitive work analysis (CWA). The tenet of CWA is to design artifacts that provide as adaptable and flexible (inner) systems as possible *within* the "possibility space" defined by the demands of various situations (the outer systems). The aim of the study is to suggest a method that allows empirical studies of C2 from a design perspective.

C2 Systems and Military Missions as Artifacts

An artifact is something that is man-made. People construct artifacts in order to facilitate the attainment of goals they pursue. Artifacts are not necessarily objects; a work procedure, for instance, is also an example of an artifact (Simon, 1996). According to this definition, C2 systems and military missions are both artifacts (Brehmer, 2008, 2010).

Focusing on how things ought to be, and devising new instruments, or artifacts, in order to attain this, is the professional realm of engineering and design (Simon, 1996). It therefore seems appropriate to analyze C2 systems and military missions according to the logic of design, as proposed by Brehmer (2005, 2006, 2007, 2008, 2009, 2010).

A user wields an artifact in an environment he or she wishes to affect. This environment is called the *outer system*. The user and the artifact together make the *inner system*. The user uses the artifact to fulfill some purpose or adapt to a goal in the outer system (Fig. 1). The artifact is used to influence, to communicate with, the outer system, and may thus be thought of as an *interface* between the user and the outer system (Simon, 1996). The successful application of an artifact depends on three factors:

1. if the artifact offers the functionality necessary to fulfill the purpose, i.e. to influence the environment as desired;
2. if the artifact allows a user to perform the required tasks, i.e. if it has an adequate *user* interface (not to be confused with the interface to the environment discussed here);
3. if the user has acquired the skills necessary to perform the tasks.

The first factor concerns how well the artifact is adapted to the outer system, the second how well the artifact is adapted to the user, and the third how well the user is trained for his or her task.

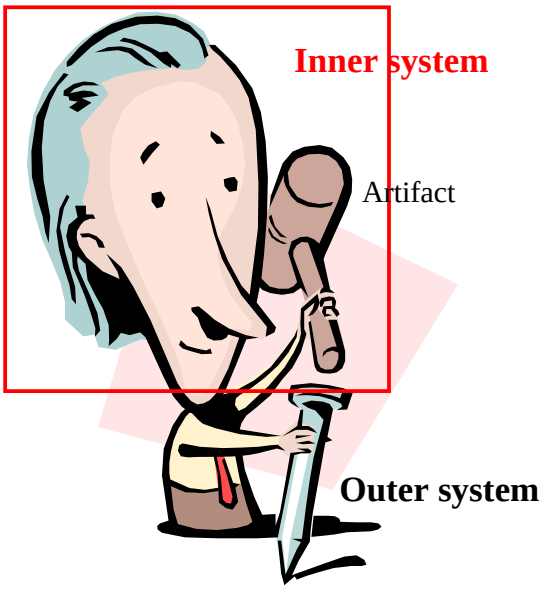

Figure 1. The artifact as the interface of the inner system to the outer system.

A C2 system is, generally, a system of systems, or C2 cells (Brehmer, 2010). These C2 cells may be organized hierarchically or in a network of self-organizing units. Each C2 cell commands some units. These units may be other C2 cells, in a hierarchical organization, or themselves, at the lowest hierarchical level.

It is important to remember that a C2 system is merely an information processing system. It does not perform any actions itself. It only produces orders to subordinate units, in the hope that actions will be performed as ordered[1]. This means that the outer system of a C2 system (or C2 cell) is its subordinate units. A C2 cell interfaces with its outer system through orders (broadly defined). A C2 system is whatever is used to produce these orders (Fig. 2).

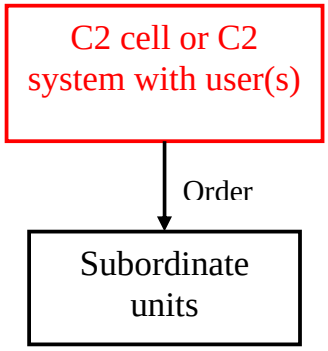

Figure 2. The inner system, the outer system, and the interface of C2.

[1] The C2 system monitors the actions carried out by the subordinates, of course. If performance is unsatisfactory or further actions required, new orders are given.

The C2 system is the artifact used to produce orders, but an order is an artifact too. This means that a C2 system is an artifact that is used to produce another artifact. When discussing C2 systems and their products, it is important to maintain the distinction between these two separate artifacts.

The purpose of a C2 system is to achieve focus and convergence, according to Alberts and Hayes (2007), or direction and coordination, in the words of Brehmer (2009), in the execution of missions. In other words, the task of a C2 system is to *design missions*. One C2 cell receives a mission from its superior command and converts it into missions to subordinate units. In this design process, the purpose is to accomplish the received mission with the available resources. In this analysis, the own subordinate units make the *inner system*, the tool used to bring about the desired effects in the outer system. The *outer system*, in this case, is the environment one wishes to change. Note that the reasoning this far refers to all C2 systems, in any organization, not just military ones.

In military missions, the environment tends to include active and/or potential trouble makers. One purpose of the mission is generally to persuade these people to stop making trouble, or to dissuade them from starting. The inner system (the own units) interfaces with the outer system, the environment, through its actions on this environment (Fig. 3) (Brehmer, 2010).

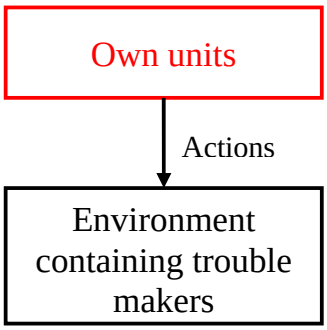

Figure 3. The inner system, the outer system, and the interface of a mission.

Applying an CWA Abstraction Hierarchy to C2 Systems and Military Missions

To analyze an artifact, or a system, according to the logic of design means, roughly, to identify the *purpose* of the system, i.e. *why* it exists (or needs to be constructed), the *functions* required to achieve the purpose, i.e. *what* the system should be able to do, and the *form* necessary to fulfill the functions, i.e. *how* this is (or could be) realized (Brehmer, 2006, 2007, 2009, 2010).

The three conceptual levels of design logic described by Brehmer are inspired by Rasmussen's abstraction hierarchy (Brehmer, 2006), which consists of five levels of abstraction (Rasmussen, 1985; Rasmussen, Pejtersen, & Goodstein, 1994). In Rasmussen's abstraction hierarchy, there is a level of measures for prioritizing among

the purposes (there tends to be more than one), and for assessing and ascertaining the fulfillment of the functions. There are also two levels of abstraction for the form element (Fig. 4).

Functional Purposes
Values and Priority Measures
Purpose-related Functions
Object-related Processes
Physical Objects

Figure 4. The five levels of the abstraction hierarchy (Naikar, Hopcroft, & Moylan, 2005).

I will start by discussing the topmost three levels, and how they apply to mission design. My aim is to provide a more concrete picture of what applying the logic of design to C2 might involve. In this I rely heavily on the conception of Naikar, Hopcroft, and Moylan (2005). They describe and explain, in great detail, the first stage of the CWA, the work domain analysis. This is the stage in which the abstraction hierarchy is constructed.[2]

Functional Purposes

When designing a system to accomplish a mission, the obvious primary objective is to accomplish the mission. There are, however, a range of secondary objectives that need to be considered, such as, for example to minimize the expenditure of money, time and human lives. These are examples of constraints imposed by the inner system (the own resources).

To complicate matters further, there are also the external constraints imposed by the outer system, the environment one wishes to affect. There is the general military objective of deterring people from making trouble, and convincing them to behave in a more desirable manner. In addition, there are secondary objectives, such as avoiding collateral damage, and gaining and maintaining the approval and support of civilians, locally as well as globally. The objectives of other agents in the area, laws and regulations, and the local terrain and climate, are also factors that have to be considered.

This is where the interface demands are defined, i.e. what effects the inner system should be able to bring to the outer system, and what obstacles it will need to manage when doing so. The level of functional purposes describes the factors that affect the how the inner system interfaces with the outer system.

[2] A complete CWA consists of five stages: work domain analysis, control task analysis, strategies analysis, social organization and cooperation analysis, and worker competencies analysis (Vicente, 1999).

Values and Priority Measures

At the level of functional purposes, all the desired capabilities of the system are listed; the ideal system is dreamed up. If the functional purposes level is a wish list, the level of values and priorities measures is where realism enters. This level represents criteria for measuring how well the system is fulfilling its purposes. What values does the system have to achieve in order to fulfill the purposes? Some measures may be relevant to more than one purpose, but the fulfillment of all of the purposes ought to be in some way measurable.

It will not be possible to achieve perfection in every respect. The acceptable range of performance for the various measures needs to be considered. The objectives will sometimes be in conflict. Is it more important to save time than to avoid risk? What is the tradeoff between getting at the trouble makers and avoiding collateral damage? This level of the analysis is where priority issues should be addressed.

The values define what the functions of the system (the next level in the abstraction hierarchy) should deliver, but also, and this is important, what the functions require in order to be able to make this delivery.

Purpose-Related Functions

The level of purpose-related functions defines the functions that are necessary (and sufficient) to fulfill the purposes. The functions are described as black boxes; at this stage it is only determined *what* the system has to do in order to produce the desired effects. The functions are described as input-output relations; this function shall with this input produce that output. How this is to be attained is decided first in the next step, when the form of the system is defined.

Jenkins, Salmon, Stanton and Walker (2009) translate the approach of effects-based operations (Smith, 2003) to missions into CWA terms. They define the desired *end state* as the functional purpose, the desired *outcomes* as the values and priorities measures, and the required *effects* as the purpose-related functions. This means that they limit the scope of the analysis to the primary purpose, and exclude any secondary purposes, as well as external constraints. Some outcome is, of course, desired, but there tends to be a limit to the cost that can be carried.

The required capabilities listed in Swedish doctrines covers quite nicely, I think, the functions required in most military missions. One of these functions is, just as noted by Jenkins et al. (2009), to deliver the desired *effects*. What effects that are desired will, of course, differ from mission to mission. Furthermore, there might be a need for *movement*, for *protection*, for *endurance*, for *intelligence*, and for direction and coordination, i.e. *C2* (Försvarsmakten, 2002, 2005).

Defining the three topmost levels of the abstraction hierarchy is to perform a requirements analysis. The functional purposes specify the system requirements, and the third level is a functional requirements specification. The second level of values and priorities measures ensures that validation and evaluation will be possible.

The form the system will take is defined in the two bottommost levels of the abstraction hierarchy, which may be viewed as a design specification.

Object-Related Processes

The level of object-related processes describes the activities performed in the system in order to fulfill the functions. "*What can be done* with the system?" is the question answered here. Note that for a system to be flexible, one-to-many relations are necessary, i.e. the system should offer several means to accomplish the functions. Some activities may also contribute to more than one function. In operating systems, there may also be activities performed that do not contribute to any of the necessary functions, and that are therefore superfluous.

Physical Objects

The bottommost level of physical objects lists *all* the components of the system that are used to perform the abovementioned activities. This includes, in addition to physical equipment, actors that manage the equipment, as well as documents describing required organization and work procedures. An actor may be a group of people or an entire organization, depending on the level of resolution of the analysis. The role of an actor may also be performed by a robot or computer software. A person may, of course, also fill this role.

The C2 System and the Mission System

A C2 cell needs to gather information on what is going on, the overall purpose, the status and activity of the units one is commanding, and what others are intending to do. The C2 unit has to plan the further use of the units it is commanding, i.e. *design their missions*. C2 as a system that gathers information and design missions echoes the functions of C2 defined by Brehmer (2005, 2006, 2007, 2008, 2009, 2010): data collection, sensemaking and planning. What is described here as mission design consists of sensemaking *and* planning. Sensemaking is in Brehmer's theory of C2, the Dynamic OODA[3]-loop (DOODA-loop), defined as "the function that produces an understanding of the mission in terms of *what should be done* in the current situation" (Brehmer, 2006, p. 9). *How* this should be done is sorted out by the planning function (Brehmer, 2006).

Sensemaking, then, entails the analysis of the topmost three levels of the abstraction hierarchy of the mission (Fig. 5). The product corresponds to a concept of operation (Brehmer, 2005). The planning function, as defined by Brehmer (2006), translates the product of sensemaking into orders. In other words, planning is the function that designs how the available resources are to be used in order to fulfill the functions of the concept of operation (Fig. 5).

[3] The name "the Dynamic OODA-loop" suggests a closer relation to Boyd's original OODA-loop than is actually the case. I therefore refrain from spelling out the acronym OODA. See Brehmer (2005) for a comprehensive treatment of the DOODA-loop's relation to the OODA-loop.

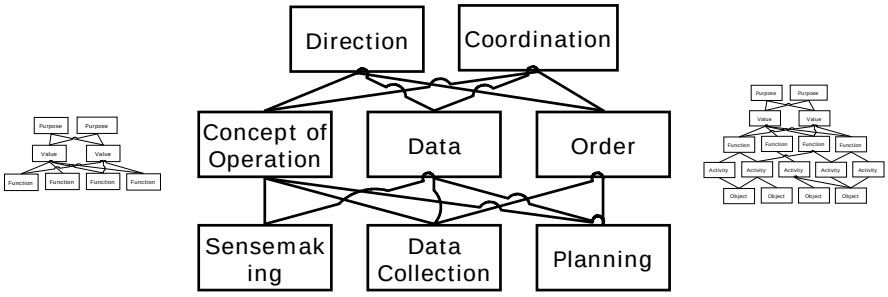

Figure 5. The products of sensemaking and planning in mission design.

The Interaction with the Opponent

As mentioned earlier, the trouble makers are (an important) part of the outer system. They try to bring about effects in the same environment as the own units, and both sides are trying to oppose the effects of each others actions. The own units are, similarly, part of the opponent's outer system. Brehmer (2004) illustrates this as two decision loops that meet in the operational theatre (Fig. 6).

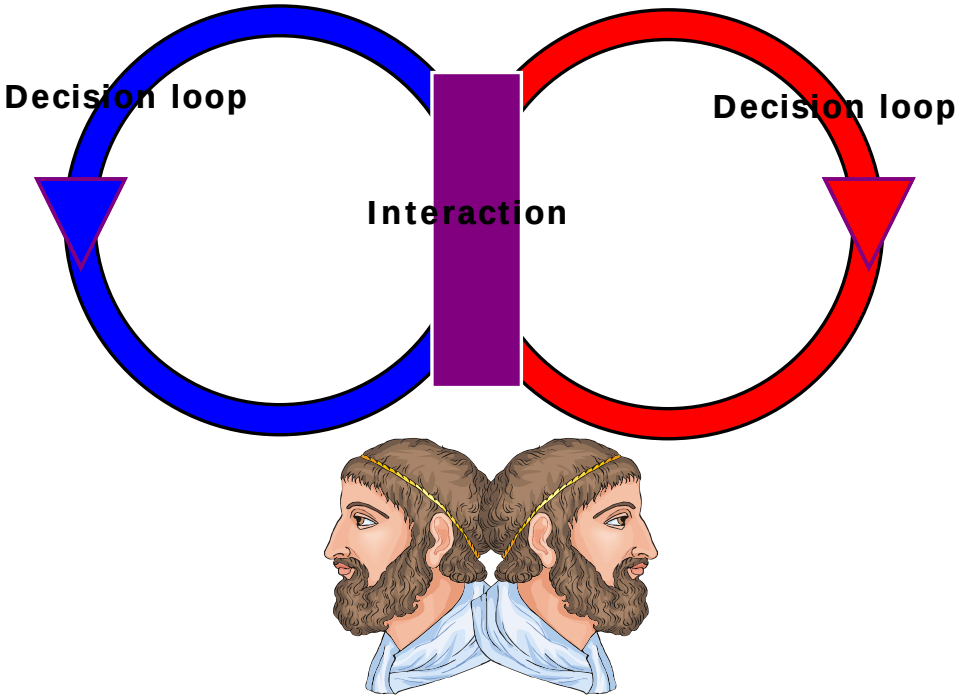

Figure 6. The need to mind the minds of both oneself and the opponent (adapted with permission from Brehmer, 2004, and Brehmer, 2009).

Brehmer (2009) expresses this as a question of being simultaneously inwards and outwards looking, illustrated (as in Fig. 6) by the Janus face.

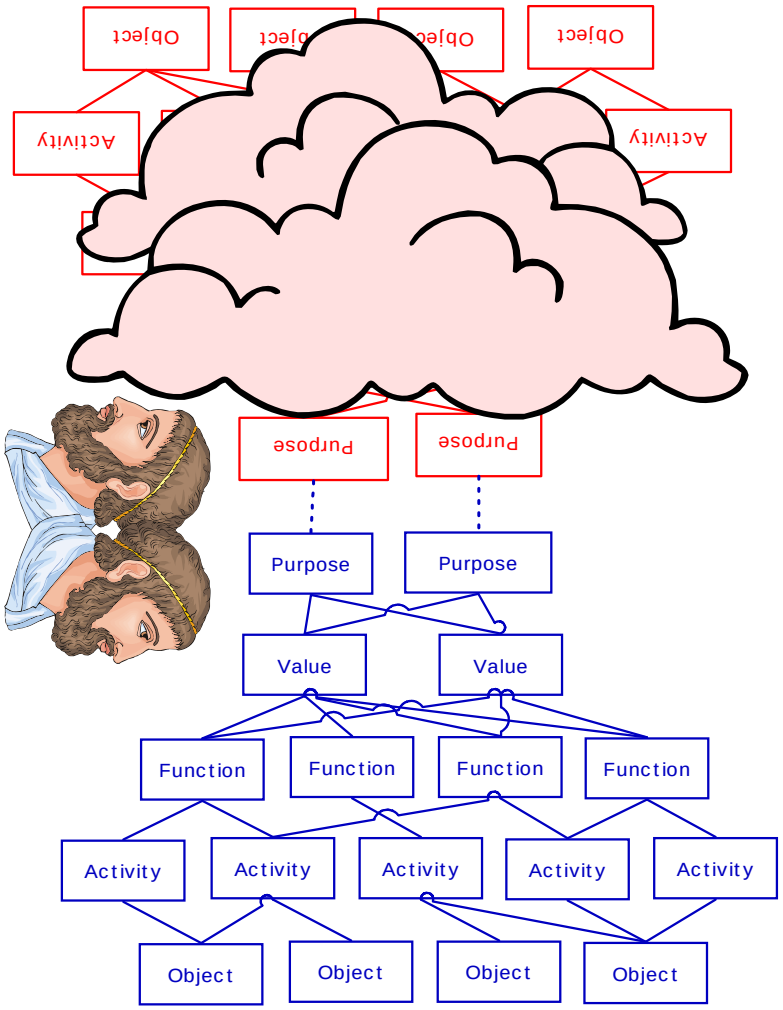

Figure 7. Designing the own mission in view of the presumed mission of the opponent.

The same method may be applied to the analysis of an opponent's mission. This will, naturally, involve a certain amount of guessing. Opponents tend to do their best to obscure their intentions. The design of a mission will be directed by assumptions on the purposes and priorities, functions, activities and resources of the opponent (Fig. 7).

Theory and Design of C2 Systems

According to Brehmer (2009, 2010), a theory of C2 should define the purpose of C2, and the functions required. These are expected to be fairly general and timeless. How the functions are fulfilled in a specific C2 system is a matter of design, and may differ depending on context and time (Brehmer, 2009; Van Creveld, 1985) (Fig. 8).

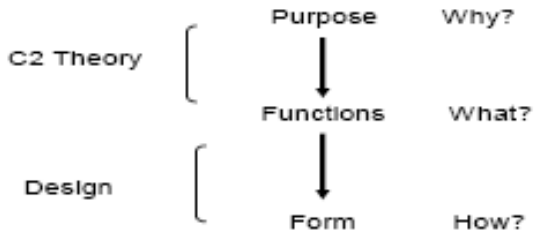

Figure 8. The logic of design applied to C2 systems (reproduced with permission from Brehmer, 2009, p. 2).

C2 systems are similar because they all need to fulfill the same functions in order to fulfill the purpose of C2. What makes C2 systems different are context specific requirements and constraints (Brehmer, 2006, 2009). Brehmer (2009) identifies five factors that shape the design of a C2 system, when the functions of a C2 system are realized in physical form. The factors are: command requirements, command possibilities, technology, command culture, and legal requirements.

For a comprehensive theory of C2, it is necessary, albeit not sufficient, to define the primary purposes of a C2 system together with the functions necessary and sufficient to fulfill these purposes. All parts of the topmost levels of Rasmussen's abstraction hierarchy (Rasmussen, 1985; Rasmussen, Pejtersen, & Goodstein, 1994) needs to be included. This means that secondary objectives and external constraints should be included at the topmost level of the functional purposes.

Command requirements, command culture, and legal requirements are examples of such secondary objectives and constraints. Technology is included with available resources, and, in the hands of the opponent, with command requirements. The available resources are, by design (when the functions are realized in form) made to offer command possibilities.

Furthermore, the second level of values and priority measures has to be described for a theory to be truly useful.

Conclusions

In this paper, C2 is described as a system (of systems), or artifact, that is used to construct another artifact. If we return to the analogy with the man applying a hammer to a nail in Figure 1, a C2 cell can be illustrated as in Figure 9. The C2 system in this cell is the artifact corresponding to the computer. The user, the person, uses the C2 system to produce another artifact, the order. The C2 system is the artifact used to produce the order, and the order is the artifact used to make the own units (own resources) act on the opponent. In this analogy, the order tells the hammer to hammer on the nail, and also *how* to do this. This is a rather more abstract illustration than Figure 1, with the user hammering on the nail. Yet, it does describe getting results from action at a distance

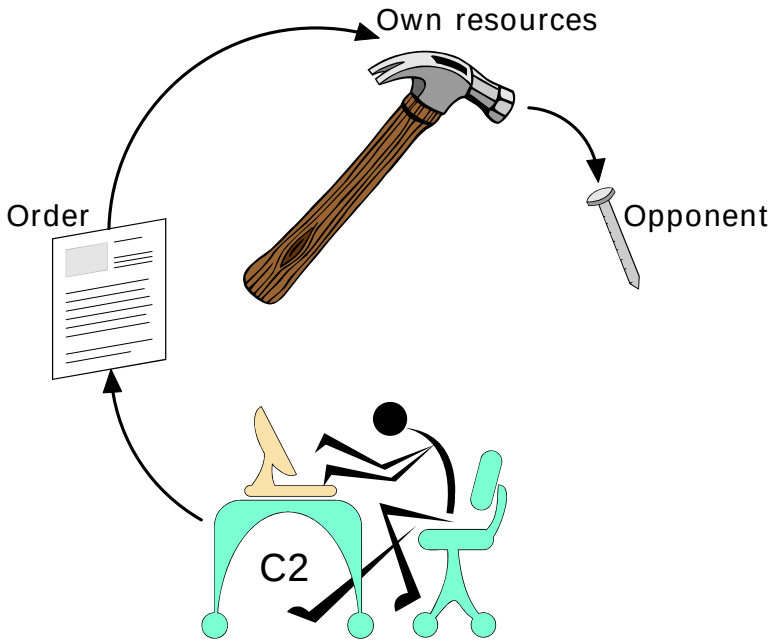

Figure 9. The separate roles of the C2 system and the order in producing effects.

These two artifacts, the C2 system and the product of the C2 system, the order, have both to be considered when addressing issues relating to C2. In this paper, I have argued that the C2 system and the orders need to be analyzed separately, and I also hope to have given more concrete meaning to the concept of C2 as design.

References

Alberts, D. S., & Hayes, R. E. (2007). *Planning: Complex Endeavors*. Washington DC: CCRP.

Brehmer, B. (2004). Tid i det nya kriget - den dynamiska beslutscykeln som ett alternativ till OODA-cykeln [Time in the new war - the dynamic decision loop as an alternative to the OODA loop]. In G. Artéus & B. Brehmer (Eds.), *Det nya kriget*. Stockholm: Försvarshögskolan.

Brehmer, B. (2005). *The Dynamic OODA loop: amalgamating Boyd's OODA loop and the cybernetic approach to command and control.* Proceedings of the 10th International Command and Control Research and Technology Symposium, McLean, VA.

Brehmer, B. (2006). *One loop to rule them all.* Proceedings of the 11th International Command and Control Research and Technology Symposium, Cambridge, UK.

Brehmer, B. (2007). Understanding the functions of C2 is the key to progress. *The International C2 Journal, 1*, 211-232.

Brehmer, B. (2008). *Command and control research is a "science of the artificial"*. Proceedings of the 13th International Command and Control Research and Technology Symposium, Seattle, WA.

Brehmer, B. (2009). *From functions to form in the design of C2 systems.* Proceedings of the 14th International Command and Control Research and Technology Symposium, Washington, DC.

Brehmer, B. (2010). *Command and control as design.* Proceedings of the 15th International Command and Control Research and Technology Symposium, Washington, DC.

Försvarsmakten. (2002). *Militärstrategisk doktrin [Military Strategic Doctrin]*. Stockholm: Förvarsmakten.

Försvarsmakten. (2005). *Doktrin för gemensamma operationer [Doctrin for Joint Operations]*. Stockholm: Förvarsmakten.

Jenkins, D. P., Stanton, N. A., Salmon, P. M., & Walker, G. H. (2009). *Cognitive Work Analysis: Coping With Complexity*. Farnham, Surrey, England: Ashgate.

Naikar, N., Hopcroft, R., & Moylan, A. (2005). *Work domain analysis: theoretical concepts and methodology: DSTO-TR-1665*
Fishermans Bend, Australia: Air Operations Division, DSTO Defence Science and Technology Organisation.

Rasmussen, J. (1985). The role of hierarchical knowledge representation in decision making and system management. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-15*, 234-243.

Rasmussen, J., Pejtersen, A. M., & Goodstein, L. P. (1994). *Cognitive Systems Engineering*. New York: Wiley-Interscience.

Simon, H. A. (1996). *The Sciences of the Artificial* (3rd ed.). Cambridge, MA: MIT Press.

Smith, E. A. (2003). *Effects Based Operations: Applying Network Centric Warfare in Peace, Crisis, and War*. Washington DC: CCRP.

Van Creveld, M. (1985). *Command in War*. Cambridge, MA: Harvard University Press.

Vicente, K. J. (1999). *Cognitive Work analysis: Toward Safe, Productive, and Healthy Computer-Based Work*. Mahwah, NJ: Lawrence Erlbaum Associates.