Modelling command and control: The challenge of integrating structure and behaviour[☆]

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Abstract

This paper presents an introduction to why it is difficult, and still desirable, to integrate the perspectives of structure and behaviour when modelling command and control (C2). We use basic systems theory in combination with theories from the field of C2 as underpinning for our arguments. The structural perspective is necessary to describe the organization of, and relation between, entities relevant for C2. The behavioural viewpoint is necessary to put focus on the purpose of C2, which is to enable an adequate response to a problem or a situation at hand. The various problems are typically of a complex character, which includes dynamic changes and therefore has to be handled with feedback, or cybernetic, approaches. However, structure and behaviour are not easy to integrate, as will be evident in this paper.

Keywords: Cybernetics, Command and Control, Feedback, Model, Structure, System.

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1. Introduction

Kinetic (e.g. warships, air-crafts, battle tanks) or non-kinetic means (such as information warfare and cyber operations) are necessary to create effects in a future operational environment. We will call these means the *execution system*. Yet alone, these means create nothing by themselves; they must receive direction and coordination to generate purposeful actions in an operational environment. Commanders, their staffs, methods and doctrines, organization, and supporting technology (e.g., command posts, means for decision support, and communication artefacts) are lame without the "muscles" provided by the execution system. We will denote these entities necessary for implementing directions; the *C2-system*. Together, these two interrelated systems are parts in a wider (or supra-) system that has the ability to act and create desired outcomes in the operational environment. We will name this system, the *mission respondent system*. In this paper, the C2-system is our primary system of interest (SOI), but it is inevitable to consider the surrounding systems to make this analysis purposeful.

We adopt the perspective on C2 given in Brehmer [1] that C2 is "a human activity that aims at solving (military) problems. Put differently, C2 is concerned with design and execution of courses of action to achieve (military) goals". Using design logic (purpose, function and form), the purpose of a C2 system is "to provide direction and coordination for the force". Before we examine the characteristics of structure and behaviour when modelling C2, we find it suitable to initially reflect upon the term "system" and some concepts.

2. Some concepts related to systems

The different meanings of the term 'system' and its dependencies are so diversified it is beneficial for us to agree upon a basic definition. An example of a commonly used and a general definition of "system" is provided by the International Council of Systems Engineering (INCOSE) [2, p.265]:

> An integrated set of elements, subsystems, or assemblies that accomplish a defined objective. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements (INCOSE)
> A combination of interacting elements organized to achieve one or more purposes (ISO/IEC/IEEE 15 288) [3, p.9]

General definitions like the one presented above often suffer from that they are "loose", which is good when reaching consensus of the meaning of a term. However, as Wasson [4, p.3] points out, a too general definition of what a "system" encompasses does not express what a system is, why it exists, whom it serves, its operating conditions, required outcomes and performance, criteria for success, etc. Since our main interest is the design of purposeful C2 systems, a complementary definition is provided by Wasson that fulfil our requirements for further discussion [4, p.3]:

> An integrated set of interoperable elements or entities, each with specified and bounded capabilities, configured in various combinations that enable specific behaviors to emerge for Command & Control, C2 by Users to achieve performance-based mission outcomes in a prescribed operating environment with a probability of success.

This definition provides both the key elements that define systems in general, the behaviour of the system of interest, and its *purpose*. However, for a system to fulfil its purpose, the system's performance also need some measures that can confirm its level of success.

Our departure, when considering systems and their characteristics, can be derived from Flood and Carson [5]. Hence, we have adopted their proposed vocabulary and definitions when considering system boundaries as well as different levels of environments that a system interacts with. Consequently, the term "boundaries" is extended to contain "narrower system", "wider system", "environment", and "wider environment."

2.1. Characteristics of a structure model and a behaviour model

As a system also can be considered as a representation of a situation, it is assembled by components that are related to an organised whole [6]. Accordingly, systems have several basic properties that inevitably have; however familiar, influence on the mindset that follow when using the system approach in the domain of C2.

In figure 1 the respondent system is in focus; therefore, the C2-subsystem and the execution subsystem can be regarded as components of the respondent system. However, our interest and focus here is the C2-system and accordingly we will regard execution and C2 as systems of their own right. In addition, the systems averted to and their relations are depicted. The model, adapted from Lawson [7, p.23], is a good example for displaying how to structure a purposeful system.

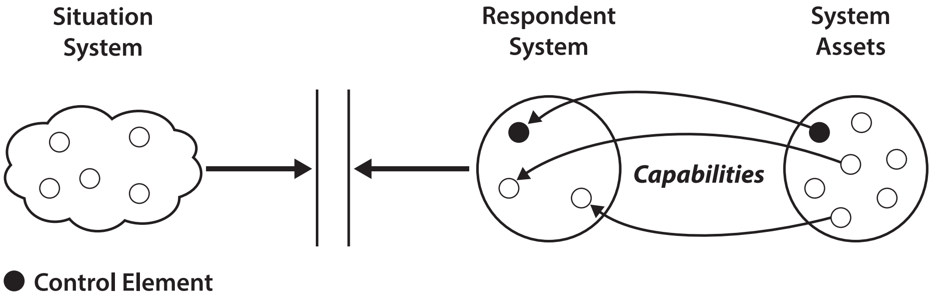

Figure 1: The System Coupling Diagram. *Adapted from* [7].

However, this type of model does not fulfil the requirements of displaying the cybernetic perspective on C2, nor does the model provide support for depicting detailed behaviour among the different systems and their parts. Furthermore, it is not recursive. Viz., in Lawson's model all elements are represented at the same level of the organisation. Thus, levels as a structure in a hierarchical organisation is not present as put forward by e.g., Stafford Beer [8, 9, 10].

A second class of system models is intended to illustrate system behaviour. The purpose of this type of models is to illustrate how systems can gain or maintain control. The most characteristic feature of these models is the cyclic or cybernetic nature with feed forward and feedback mechanisms; i.e., their striving for a self-regulating behaviour (see figure 2). In a C2 context, the controlling system must be able to examine and report the state of both itself as well as its success in affecting the environment whether it is under, on, or above the value permitted. Skyttner writes [11, p.91]:

> A comparison is made between the receptor value and a desired standard stored in the *comparator (discriminator)*. The difference provides a corrective message which is implemented by the *effector (activator)*. Through monitoring and response feedback to the receptor, self-regulation is achieved.

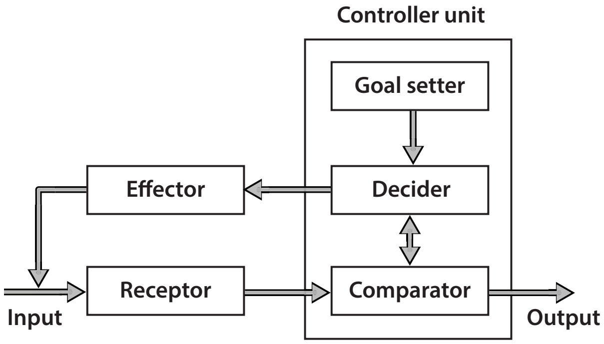

Figure 2: A general control system, *Adapted from* [11, p.91].

3. Modelling structure and behaviour in a C2-context

3.1. Application of a structural model in C2

The system coupling diagram presented in figure 1 highlights the aspects of structural design, i.e. adapting an adequate respondent system from available system assets. In figure 3 we have enhanced the design aspect by representing the defence system's available assets that are related to C2 in terms of *methods* (M), *organisation* (O), *personnel* (P), and *technology* (T). Note that the arrangement/structure of elements in the mission respondent system matches the elements in the situation system. This correspondence also illustrates how the effects of the law of requisite variety are in need to be addressed [12, 13]. These assets are used to fulfil the generic functions necessary for obtaining direction and coordination from the C2-system within the mission respondent system[14]. In this case the situation system represents an acceptable or normal condition where the mission system primarily deals with the handling of border incidents and other standard procedure actions (figure 3). This state is indicated by the green colour (neutral), with few elements that can handle the situation forming the mission respondent system.

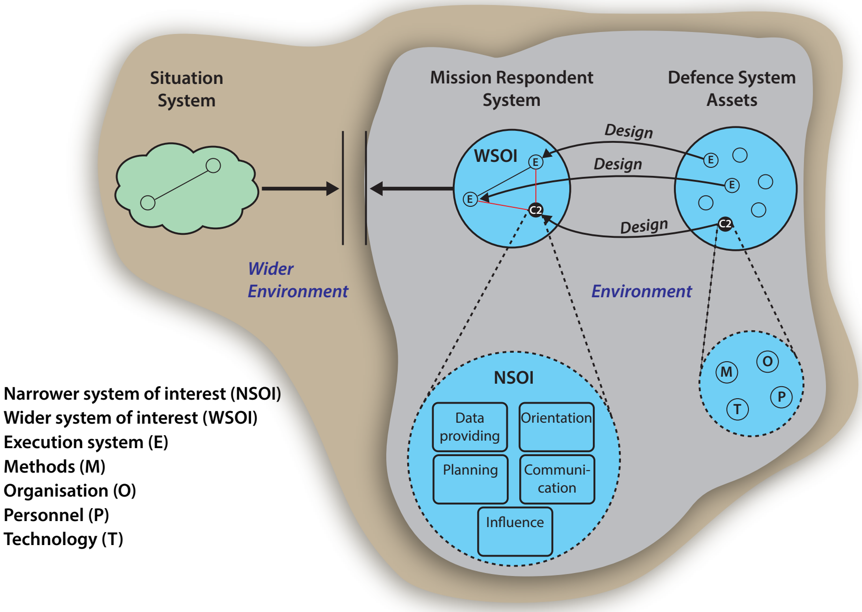

Figure 3: A mission respondent system designed to handle an acceptable situation.

In the following case (figure 4), the situation system is generating an unacceptable condition. For example, a country (represented by the environment in the model) is under armed attack, which might result in a state of conflict. Our (blue) response is to design an enhanced mission respondent system with more assets, both C2 and execution assets obtained from the defence system.

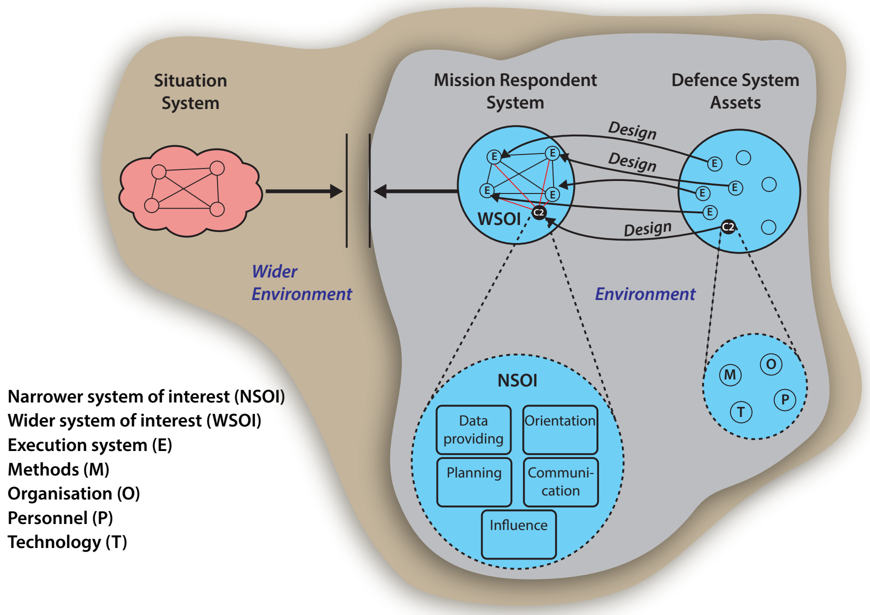

Figure 4: A mission respondent system designed to handle an unacceptable situation.

3.2. Application of a cybernetic model in C2

Figure 5 displays our effort to adapt the dynamic OODA-loop (DOODA), [1] originally developed by Brehmer [e.g., see 16, 17]. Our updates include the process-steps of "influence" and "communication" which not has been published as steps in the DOODA-loop before (only as grey boxes or as functions [18]. Further, we have put the updated DOODA-model in a systemic context (with terminology in accordance with other models in this paper). The C2-system (SOI) is placed in the center of the model. It has a linkage (relation) to the execution system and both systems are contained in the mission respondent system (WSOI). The mission respondent system generates effects in the operational (wider) environment with the purpose of controlling the disturbance caused by the antagonistic situation system.

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[1] The name; the dynamic OODA loop, is an homage to colonel Boyd's well known OODA-loop (observe, orient, decide, act) [15].

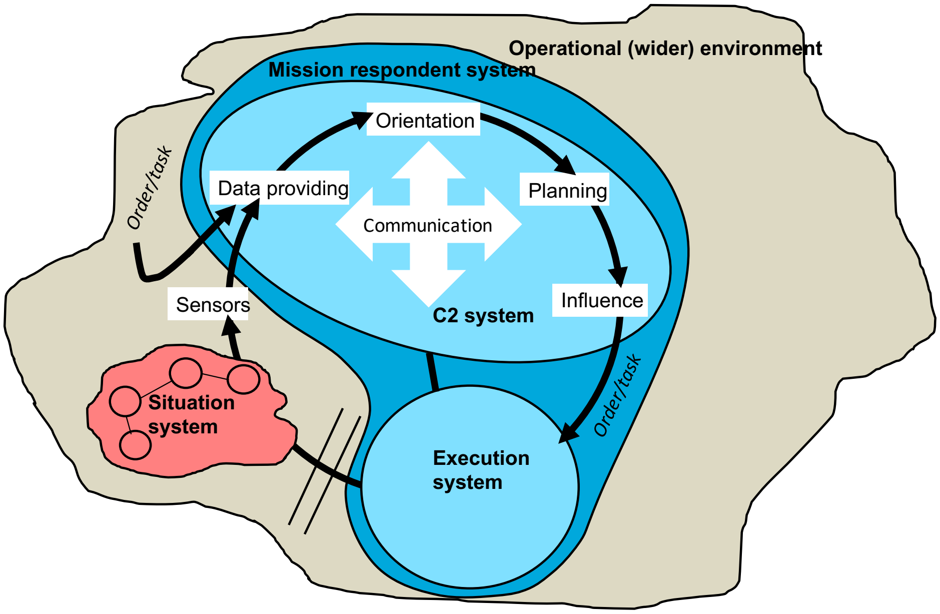

Figure 5: The adapted DOODA-loop in a relevant systemic context.

The C2-system receives data (input) from the operational environment via the sensors and also as orders or tasks from the C2-level above (start condition for the C2-system). The *data providing process* (each process-step in the DOODA-loop could alternatively be regarded as subsystems or components dependent on preferred view) transduce the data to the form required by the *orientation process*. The orientation process is primarily occupied with problem solving and decision making and provide an answer to the question; what should be done?

This process also decides when a mission is completed/fulfilled which is the stop condition for the C2-system. The answer could be in the form of a chosen course of action and a concept of operations. The planning process transduce the products received to a coherent plan by synchronising and coordinating available resources (assets) in time and space (how should it be done?). The *influence process* is dependent on a valid mandate to direct and provides leaderships aspects in the dialogue with subordinate levels of C2 or members of (recipients in) the execution system. The typical product from the influence process, and indeed the main output from the entire C2-system, is a formalised order or task. The last necessary and sufficient process is the communication process. We have chosen to illustrate it in another way than the other process-steps because it takes place within the C2-system (between the other process-steps) as well as between the execution system and the C2-system (e.g., as reports from the execution system).

Both the communication process and the influence process are the results of an awareness (by the authors as model designers) that it exists an implicit structure in terms of hierarchies in the mission respondent system. Note this is valid even in a truly self-synchronised [e.g., see 19, 20, 21] mission respondent system, because it has to have at least one level of C2 to provide a commander's intent to the self-synchronising execution system. This is also a good example of this class of models (cybernetic) shortcomings; it is difficult to include desired structure aspects such as hierarchies and recursion.

The presented model (the adapted DOODA-loop) is an instance of the cybernetic archetype presented above. It shares the most prominent feature, which is the capacity to regulate a systems output in relation to detected changes in a dynamic environment. Indeed, the presented process-steps in the DOODA-loop have several corresponding features with the components of the cybernetic archetype model. The receptor/detector is equivalent with the "sensors," the comparator/discriminator is similar to the "data providing process," the goal setter, and the decider resemble the "orientation- and planning-processes," and finally the effector/activator is equivalent with the "execution system."

4. Discussion

So far, we have presented two basic ways of modelling C2, either by structure, or by behaviour. The structure perspective was represented by the system coupling diagram as an archetype, and the behaviour perspective was described by the general control system as an archetype. Each model class has its pros and cons and we tried to unify some of the positive features from each class when we adapted the archetypes. The system coupling diagram was enhanced by highlighting the design perspective and by applying the model to two different states in the operational environment – thereby making it useful for a varying environment (albeit two individual models were needed to do that).

The cybernetic DOODA-loop was adapted to remedy some of its shortcomings and still keep its advantages. We have therefore included the process-steps of "influence" and "communication" in the model. These two processes are partly a result of an implicit knowledge that the mission respondent system has a more or less hierarchical structure. Further, we have placed the DOODA-loop in a relevant systemic context to make its relations to other systems clearer – i.e. bringing a little bit more structure to the model.

Sometimes people say that the phenomena of the world can be described in many ways and that it really does not matter very much how it is done. It is just a description. This standpoint is wrong. Phenomena of the world can be described in many ways – but sometimes it makes all the difference how it is done. We have described throughout this paper how the C2-system and the execution system, with its multiplying relation, together create a potent mission respondent system to cope with complex problems in the operational environment. Without this specific description, how could the following question be answered. What is a good C2-system or what is good performance of C2? If one for instance would measure the effects generated by a mission respondent system, how can you tell whether the effects were caused by good performance of C2 (or a well-designed C2-system), or by some other factor related to the execution system, the situation system, or perhaps to something else in the operational environment? – You cannot. If we are interested in enhancing C2-performance, we have to specify and describe that specific C2-system, in a systemic relevant manner, to be able to make conclusions in any direction.

So, what class of models is the most useful? Are their respective typical features possible to unify in one model? We believe that the answer should be derived from the purpose of C2 as mentioned in the introduction [1] "a human activity that aims at solving (military) problems." Military problems are more or less of a complex character, and they are definitely dynamic since the operational environment is dynamic. This leads to the conclusion that useful models of C2 should be able to manage a dynamic environment. This in turn indicates that some sort of cybernetic model, dedicated to handle feedback effectively, should be the departure of further development. However, structural models have desirable features too, as shown above. We consider it possible that more relevant structural features such as hierarchy and recursion, could be integrated in for instance the adapted and upgraded DOODA-loop. This will be a suitable challenge for future research.

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