23rd ICCRTS

Design logic in practice:

A method to extract design criteria for future C2 systems

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Abstract
The world we live in is a complex system tinged with constant change. In order to cope with this fact, a defense mission system needs to adapt to these challenges. The command and control (C2) system is the component of the defense mission system that is our system of interest, our unit of analysis, in this paper. We present a first attempt to use a method based on design logic complemented with scenario driven exercises, to extract requirements and more fine-grained design criteria to enhance design of future C2 systems.

As a starting point, three scenarios were developed that intended to reflect key features of future potential conflicts. A number of subject matter experts (SMEs) participated representing strategic, operational and tactical levels of command. The SMEs were asked to state their C2 requirements in each of the scenarios. The resulting set of C2 requirements were analyzed to find design criteria pertaining to the general C2 functions (Data Providing, Orientation, Planning, Influence, and Communication) in Brehmer´s design-logic hierarchy (Purpose, Function and Form). The results indicate that the method can be usefull to find requirements and design criteria for future C2-systems.

Introduction

To meet new challenges in the operational domain Swedish Armed Forces (SwAF) perceives a need to advance several of its capabilities, such as the C2 capability. However, the development of the current SwAF C2 system has to a large extent been driven by advances in the technical domain without a systematic approach to system development and requirements analysis (Försvarsmakten, 2015). Currently, a large comprehensive study is conducted that aims to develop a new C2 concept to be implemented during the 2025-2035 period. That work involves a number of smaller studies, several of which focus on the expected demands on future SwAF C2. This paper is based on one of these studies (Andersson & Spak, 2016) and describes a method to elicit design criteria using scenario driven exercises. In the present study, the framework of C2 theory and design logic (e.g. Brehmer, 2007, 2010, 2013; Jensen 2012; Spak, 2017) was applied as an analysis tool.

The theory of C2 functions and design logic

The C2 system is the artifact in focus of the analysis and its purpose is to provide direction and coordination for the military units. According to Brehmer´s C2 theory a number of independent functions are needed to achieve the purpose of direction and coordination. One function concerns *Data providing*, which pertains to collection of data from the operational environment (regarding adversaries, own troops and other relevant features of the environment), data processing, and dissemination of data/information that are needed for preparation and execution of the operation. The resulting product, which may materialize as for instance an operational picture or as answers to commanders information needs, will act as input to the *Orientation* function.

The Orientation function produces action-oriented understanding of the situation, given the mission. An action-oriented understanding of the situation implies an understanding of what is possible and necessary to do, to fulfill the mission under the current and probable future circumstances. The resulting product could be a Course Of Action (COA) or a Commander´s Intent. The Orientation function also identifies what additional information is needed in order to reach the action-oriented understanding, being materialized as for instance Commander´s Critical Information Requirements (CCIRs). Thus, the products from the orientation function act as input to the Data providing function, as well as to a *Planning* function.

The planning function transforms the CoA into a fully developed plan by synchronization of the units and by evaluation of the plan. In order to ensure that the plan is effectuated an *Influence* function is needed. By the military mandate the influence function yields the plan the status of an order that is to be executed by lower C2 levels and ultimately by the military units. The influence function also contains leadership aspects to enhance motivation.

The above four functions (Data providing, Orientation, Planning, and Influence) pertains both to the C2 system seen as one entity and to the command level specific C2 systems. For the C2 system seen as one entity, encompassing all the level-specific C2 systems, a fifth function is needed. This function concerns *Communication* between and among the level-specific C2 systems, as well as between the C2 system and the military units.

At the level of form, the C2 system comprises various support systems (technology) and methods as well as organization and personnel that together fulfill the above-mentioned functions. For instance, the orientation function may be fulfilled by the commander, supported by his or her staff, which in turn may be supported by various analytical methods and technological support systems. For an overview of the C2 functions and the systemic approach, see figure 1 (adapted from Spak, 2017, p. 7).

Design logic (Brehmer, 2007, 2009, 2013; Jensen 2012) is a tool for analyzing existing artefacts as well as for creating and developing new artifacts. A design logical analysis pertains to characterization of the artifact at three conceptual levels.[1] The top level concerns the *purpose* of the artefact and describes *why* the artifact exists or why it should be created. The next level concerns which *functions* are needed to achieve the purpose, i.e. *what* the artifact must be able to produce in order to fulfill its purpose. The last conceptual level in the design logical analysis concerns the actual *form* of the artifact. The form level describes *how* the functions are fulfilled. For an overview of the design logic hierarchy, see figure 2 (includes an example regarding eliciting design criteria for an operational picture derived from the present study).

When developing an existing artifact, or creating a new one, the level of purpose is the starting point. Further, the functions necessary to fulfill the purpose are identified. The actual design process pertains to finding or inventing form-level elements that can fulfill the functions. A particular function may be fulfilled by several alternative form elements.

[1] Brehmer´s design logical scheme is in large inspired by Rasmussen´s abstraction hierarchy (Rasmussen, Pejtersen, & Goodstein, 1994; see also Naikar, Hopcroft & Moylan, 2005).

Figure 1. The functional structure of the C2 system: possible subfunctions and systems approach.

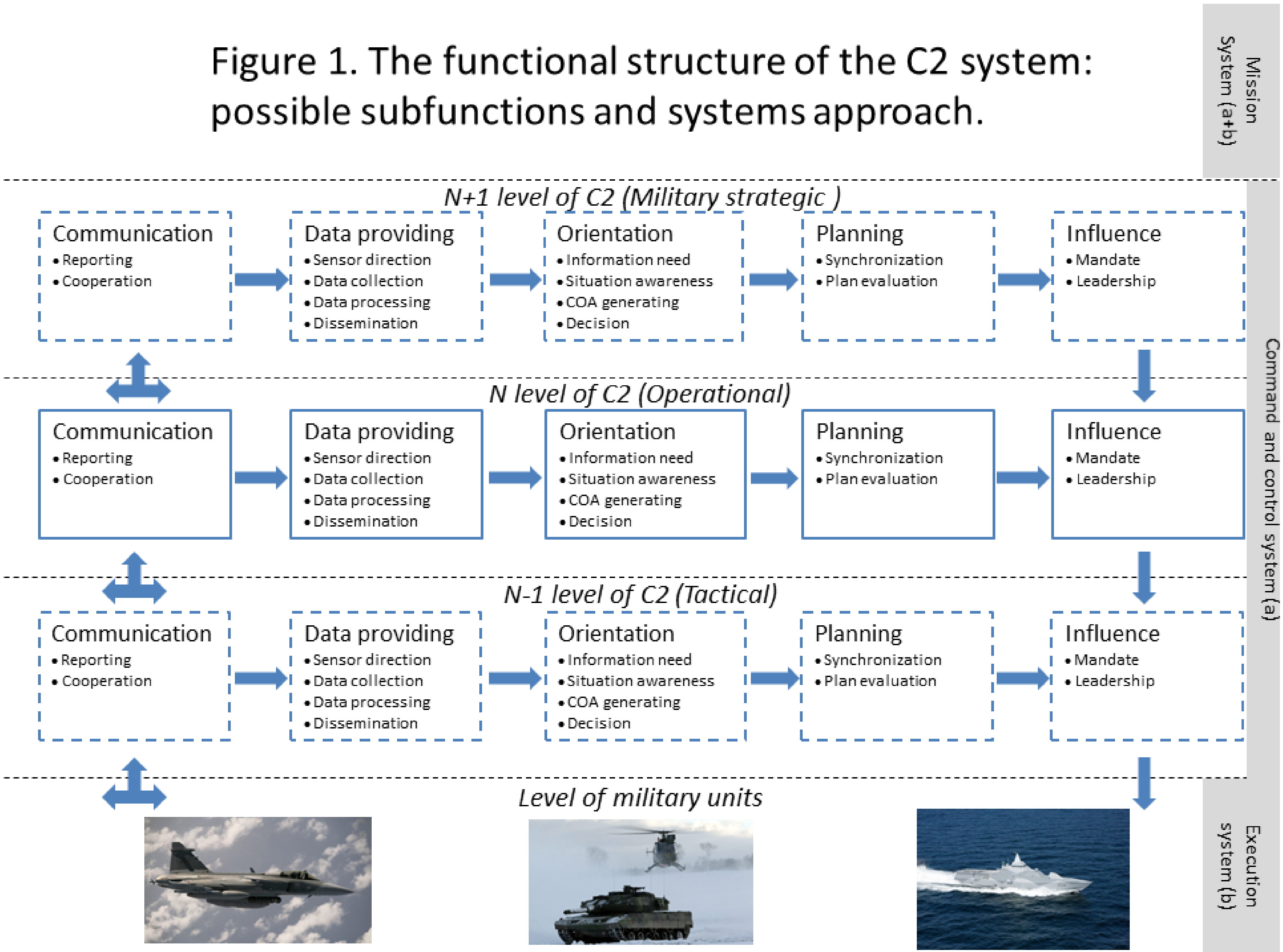
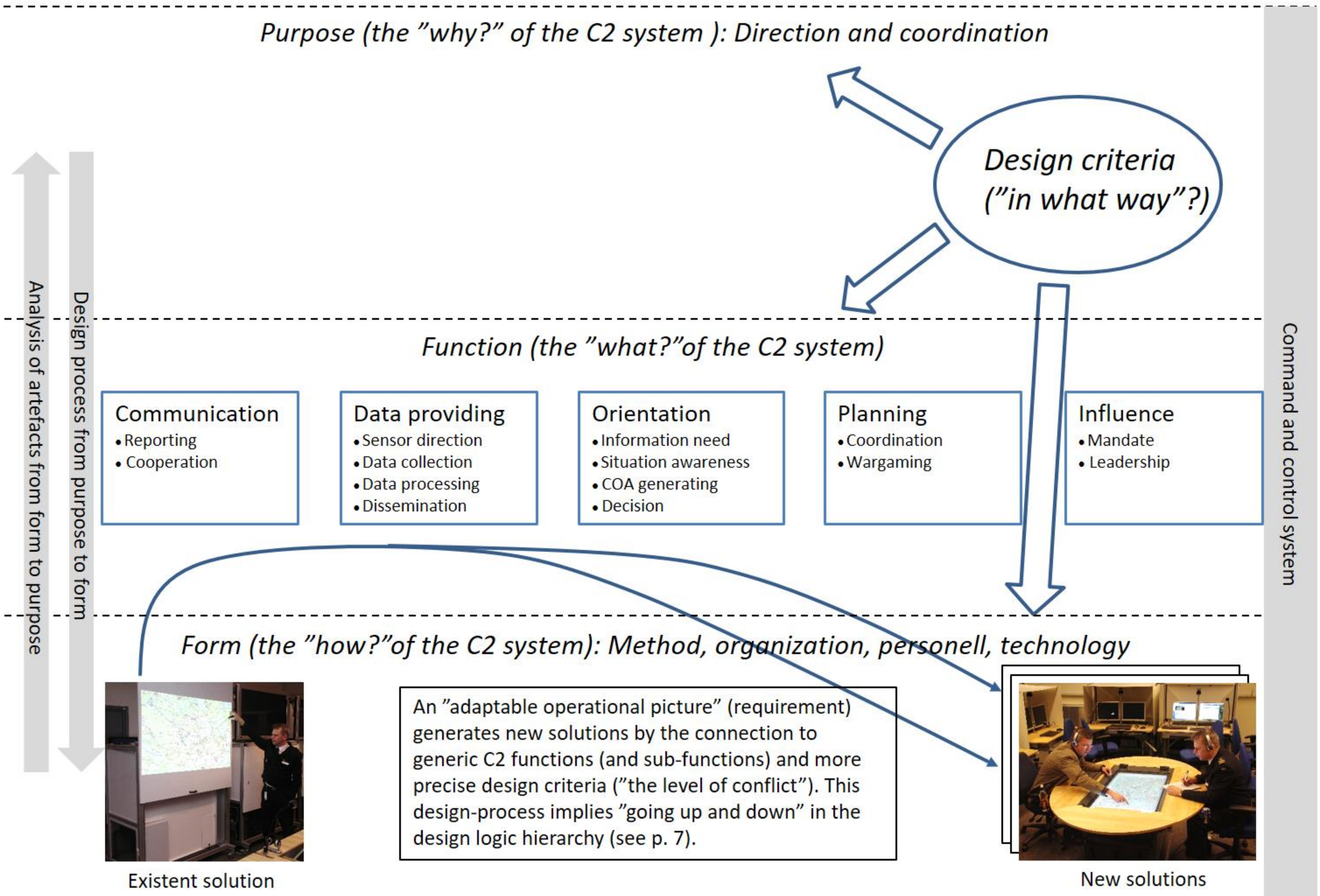


Figure 2. The design logic hierarchy.



In the design process, a class of qualifiers may complement the three conceptual levels of purpose, function, and form. The qualifiers, which are labelled *design criteria*, concerns specific requirements or constraints *in what way* the purpose of the artifact ought to be achieved. Further, design criteria must be operationalized and measurable (in contrast to more general requirements) in order to be useful for design purposes (Brehmer, 2013; see also Hallberg, Granåsen, Josefsson, & Ekenstierna, 2018 for a comparison with a systems engineering perspective). Design criteria may originate from the users of the artifact, or from the environment in which the artifact is meant to achieve its purpose. The design criteria helps the designer to select among potential form elements and the resulting artifact would be better suited to both user-needs and to the particular environment in which the artifact will be used.

For instance, to fulfill the Orientation function the commander and his or her staff may not need analytical methods to arrive to an action-oriented understanding. Instead, it may suffice with adequate training or personal experiences of similar situations. Indeed, such a solution may be even better in time critical situations. By focusing on the functions, and deliberating on the various ways they could be actualized, the designer or developer may find solutions that are quite different from previous instantiations of the system.

Method

As mentioned in the introductory section, the present paper is based upon a study whose purpose was to find requirements and elicit design criteria that, in a later phase, could contribute to the development of future SwAF C2 systems. Design criteria could be elicited by a number of methods, as for instance interviews with SMEs. One potential pitfall when interviewing SMEs (in this case practitioners or users of the system) about possible future demands on the C2 system could be that their views may be constrained by experiences of current circumstances (e.g. systems functioning, operational environment and doctrine). Methods relying on practitioners experiences could help developers to modify the current system, but not necessarily to find entirely new solutions. As an attempt to remedy this, the study utilized scenario based exercises instead of traditional interviews. The scenarios were portraying possible futures, which presumably would encourage novel and innovative thinking among SMEs, and thus be more beneficial in the development of a new kind of C2 system.

Scenarios

In order to elicit a multitude of diverse and potentially important design criteria for a future SwAF C2 system, three different scenarios were used, in three separate exercises. The scenarios were constructed to capture a broad range of possible future situations that the SwAF should be prepared to address. The scenarios were developed based on an analysis of the Swedish Defence Bill 2016-2020 and of Swedish defence policy and military strategy (Edström & Josefsson, 2016). In Edström and Josefsson´s analysis, two variables were identified; *level of escalation* with *war-fighting* and *war-avoidance* as end points, and *strategy* with *offensive strategy* and *defensive strategy* as end points. Due to time limitations, only three of the four ideal types were selected for the development of the scenarios[2].

[2] The *war-avoidance defensive strategy* was considered to be of least interest in this case, and was therefore omitted, mainly because since the cold war era that kind of strategy has been the traditional Swedish approach. Thus, presumably that strategy already contributes to the shape of the

The ideal types were developed into plain text scenarios with additional context information to make them more or less realistic, albeit brief, descriptions of possible future situations. Each scenario contained a short vignette describing a global situation year 2027, threats and actions taken by an adversary towards Sweden, and planned or ongoing activities from the Swedish side. The scenarios also contained some examples of military units and equipment available to the Swedish side, and also some of the adversary's resources.

Participants

Several experienced officers at the Swedish Defence University (SEDU) participated as SMEs in the exercises. They were specialists from the strategic, operational, and tactical (Army, Navy, and Air Force) command levels. In each exercise, one or two specialists from each level and arena participated, mostly the same individuals in all exercises.

Procedure

The exercises took place at the SEDU, on three different occasions a month apart. Each exercise took about one day to accomplish. The participants, exercise managers, and the research team (the authors of this paper) were present. The single, or dyad, participants for each level and arena were seated together at a table, but performed their respective tasks separately (the dyads worked together). Before the exercise begun, the background of the study and the purpose of the exercise were explained to the participants.

Each exercise contained two phases. In the first phase, the participants were asked to perform mission analysis and develop Courses of Actions for their respective levels/arenas, based on information in the scenarios. In the second phase, which was the actual basis for data collection, the participants were asked a number of questions about their specific C2 requirements, given their mission analysis and COA. The questions concerned *who* do you command*, where* and *when* is C2 performed, *what kind of decisions are needed*, *what are the prerequisites for decision making*, and *what are your information needs*. The participants took notes of their answers.

After answering the questions separately, the participants gave an oral account for their answers and, during discussions with other participants and the exercise managers, expressed their respective C2 requirements in the scenario. In some cases, during the discussions new or more nuanced opinions of the respective C2 requirements were developed. The discussions were recorded. After the exercises, the research team analyzed the recorded answers and discussions. All utterances that the research team considered relevant for development of a future C2 concept were compiled as a list of C2 requirements.

Results

The participants expressed 109 requirements in total[3]. Several of the stated requirements were similar over the three scenarios. However, the requirements were to some extent varying which indicates that the scenarios indeed influenced the participants' views of how

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current C2 system and will probably continue to be reflected in future realization of Swedish C2 concepts.

[3] The strategic level expressed 16 requirements in total over the three scenarios, the operational level 18 requirements and the tactical level stated 20 (Army), 15 (Navy), and 26 (Air Force) requirements. During the discussions, 14 additional requirements were identified.

C2 should be performed. The requirements were expressed on the level of form (such as material objects or systems), or on the level of function (such as an ability to achieve something) in design logical terminology.

The results were analyzed in a two-step process. First, each requirement was examined regarding which of the five C2-functions it belonged to. Many of the requirements belonged to more than one function and some belonged to all functions. Next, the requirements were scrutinized regarding possible design criteria contained within the more general requirements. Since the purpose of this paper is to describe the method used, and not the full outcome of the study, only one example of the extraction of design criteria from the requirements is reported here. For the complete list of results, see Andersson and Spak (2016).

"*The content of the operational picture should be adaptable to the level of conflict*". This statement originates from the general discussion after scenario three (war-fighting+offensive strategy). This requirement was categorized as belonging to the Data providing function but also to the Orientation function, and it is expressed on the design level of form. This statement contains one general requirement: "*The content of the operational picture should be adaptable"* but also a more specific design criterion: "*to the level of conflict*". The criterion is measurable along a category scale (e.g. peace, elevated preparedness and war). If we apply the typical question related to design criteria (*"in what way?")* to the statement, the result would be: "*In what way should the content of the operational picture be adaptable to a) a peace-time situation, b) a raised level of preparedness, and c) a war-time situation?"*

Next, we ask how these instances of an adaptable operational picture could fulfill the data providing function and the orientation function with its respective sub-functions (going up in the hierarchy). This operation generates a total of 24 (3 levels of conflict X 2 functions X 4 sub-functions) new more specific questions to guide the design process – aiding the extraction of new design criteria. For example: *"In what way should the content of the operational picture be adaptable to a raised level of preparedness regarding sensor direction/data collection/data processing/dissemination?"* Or: *"In what way should the content of the operational picture be adaptable to a war-time situation regarding information need/situation awareness/COA generating/decision?"* By connecting the operational picture (an artefact at the level of form) with the level of functions and sub-functions, new possibilities may emerge (see example in figure 2). Naturally, in real life C2 system design, a team of professional designers and experienced operators would together have to articulate the detailed design criteria, possibly stemming from the questions derived from the method suggested in this paper. Nevertheless, with the purpose of displaying how the method could generate new specific design criteria, we provide an example. *"The content of the operational picture should be derived from the cooperation between agencies regarding data collection during a raised level of preparedness."*

Discussion and conclusion

The purpose of this paper was to present a method to find requirements and elicit design criteria from scenario-based exercises applying a design logical framework. This method is intended to be an alternative or complement to other methods relying on SMEs, such as various forms of interviews. This paper presents a first effort to use this method. The method presented in this paper produced 109 requirements, which either contained or could be used for extraction of design criteria, which has the potential to substantially contribute to a design process of developing a future SwAF C2 system.

This study is probably affected by some unintended factors, pertaining both to the exercises and to the method of analysis. Some factors that could have influenced the results are: a) the scenarios regarding a sufficient breadth – did they provide a broad enough possibility space, b) the way the scenarios were presented (e.g. own and adversary's resources), c) a dynamic execution phase was lacking, d) the application of a conventional hierarchical military structure, e) the number and type of participants – a broader representation may have produced more requirements and design criteria, f) the use of another framework of C2 theory (with different functions) may have altered the requirements and design criteria.

Notwithstanding the above, the first step in further research would be to compare the results from this study with results from studies based on other methods. Preferable, such an effort would involve the same participants. As mentioned above, one reason for developing this method was to avoid the pitfall of SMEs being constrained by present circumstances.

To conclude, the scenario driven exercises together with a design logical framework, were useful for identifying a multitude of requirements on a future C2 system. By displaying how the transformation of requirements, expressed by the participants, to design criteria could be done, this study contributes to the design process of adapting existent form elements, and also finding new form elements, for future C2 systems. However, this novel method needs to be further tested and developed, and its usefulness needs to be systematically compared to other methods that could potentially contribute to an effective design process.

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