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SUPPORTING THE ASSESSMENT OF ASSUMPTIONS IN COMMAND AND CONTROL

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ABSTRACT

Two interconnected challenges in C2 are to *cope with uncertainty* and to *make timely decisions*. From the standpoint of a commander these challenges may easily come into conflict with each other. Uncertainty, i.e. gaps in knowledge, may be reduced by collecting and processing additional information - but this takes time. To handle this dilemma the commander and his/her staff may have to make *assumptions*. An assumption is “a supposition on the current situation or a presupposition on the future course of events”. If the assumptions being made are invalid it may have negative consequences for the ability to reach the mission objectives. It is therefore important to *assess* and to *follow up* the assumptions during mission planning and execution, in order to make it possible for timely re-planning if necessary. However, even though the handling of assumptions is considered to be important in both NATO’s planning directive COPD and in the Swedish counterpart SPL, neither COPD nor SPL gives a clear guidance on *how* to *assess* the assumptions - apart from an exhortation to use a risk evaluation template. To date there is no theoretically grounded and systematically tested technique for assessing assumptions in C2. By using a design logic framework and techniques from the area of risk assessment this paper presents the initial step to a possible solution to these problems. The results are a design logic scheme and a design proposition for a technique that is *potentially* suitable for assessing assumptions, to be tested in forthcoming empirical studies.

KEY WORDS: Assumption, Uncertainty, Risk, Risk Assessment, Design logic

INTRODUCTION

Command and control (C2) is the function in a military system that provides direction and coordination of available resources in order to achieve formulated goals (Brehmer, 2007; 2009a; 2009b) in a complex connected battlespace. Two interconnected challenges in C2 are to *cope with uncertainty* and to *make timely decisions* during mission planning and execution. From the standpoint of a commander these two challenges may easily come into conflict with each other. Uncertainty, i.e. gaps in knowledge, may be reduced by collecting and processing additional information - but the collection and processing of information takes time, which obviously can interfere with the ability to make timely decisions in this kind of dynamic situations.

To handle this dilemma the commander and his/her staff may have to make *assumptions*. An assumption in the context of C2 is an *uncertain belief*; “a supposition on the current situation or a presupposition on the future course of events” (DOD, 2015) – regarding for example the act, capacity or location of an opponent, but also suppositions about more concrete circumstances, like the possibility to pass a bridge at a certain time. In addition to

their own assumptions a C2 staff also regularly has to process information from higher and/or lower levels of command that contains assumptions made by others. If the assumptions being made are invalid, or if they fall, it may have negative consequences for the ability to reach the objectives of a mission. It is therefore important to *handle* the assumptions thoroughly during mission planning and execution, in order to make it possible for timely re-planning if necessary (Brehmer & Thunholm, 2011; Brehmer, 2013). In this context “handling of assumptions” means to *assess*, to *follow up* and to *take action* regarding the assumptions being made, where the assessment phase precedes and constitutes the basis for determining *which* assumptions to follow up and *if* action has to be taken regarding the assumptions (figure 1). Taking action is for example to develop a response to a possible event, if an assumption turns out to be incorrect.

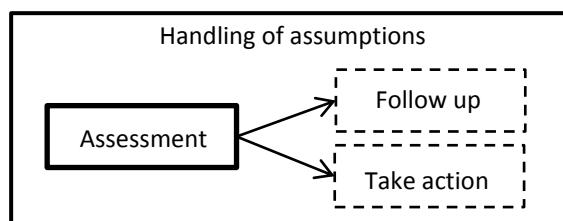


Figure 1. Handling of assumptions

In this paper I will focus on the assessment part, i.e. the process to determine *which* assumptions to follow up and *if* action has to be taken regarding the assumptions being made. The reason for this is that even though the handling of assumptions is both addressed and considered to be important, for example in NATO’s planning directive COPD (NATO, 2013) and in the Swedish counterpart SPL (Försvarsmakten, 2015), neither COPD nor SPL gives a clear guidance and support on *how to assess* the assumptions - apart from an exhortation to use a risk evaluation template (NATO, 2013; Försvarsmakten, 2015). To date there is no theoretically grounded or systematically and empirically tested technique¹ for assessing assumptions in C2 in the Swedish Armed Forces. As a consequence it is not yet known if the current method, where remaining uncertainties from the mission analysis within the operational estimate becomes assumptions and thereafter decision points and CCIR² (Försvarsmakten, 2015), is valid and reliable. Are really all key assumptions caught by this approach? How about other potentially important assumptions that are being made during the planning process, which does not become CCIR? This is not known. It is also not known if one technique works better than the other, which technique is most appropriate in different situations or the strength and weaknesses of different techniques.

However, what is known from previous empirical studies is that there seems to be considerable shortcomings regarding the handling of assumptions in C2 (Brehmer & Thunholm, 2011; Riese et. al., 2008). In the study of Brehmer and Thunholm (2011) the staffs re-

¹ Technique is the concept used here for a method or a procedure to assess assumptions.

² CCIR is the Commanders Critical Information Requirement.

ceived information indicating that the assumptions, on which they had built their plans and actions, no longer were valid. Despite this information the staffs didn't re-plan in time. Similar results were obtained in the study by Riese et. al. (2008). Hence, there seems to be a potential for improvement to current practice regarding the handling of assumptions in C2. One possible explanation for the shortcomings is that the staffs' didn't use an adequate technique for assessing the assumptions, and therefore missed that the assumptions no longer were valid. Results from previous research indicates that it is possible to achieve timely re-planning through a better handling of assumptions, by using techniques for identification and early signs related to crucial assumptions (Brehmer & Thunholm, 2011). However, these results are limited and uncertain and needs to be complemented with more systematic and controlled studies. This paper is a first step in such a work.

In this paper I will present the initial step to a possible solution to the shortcomings regarding the handling of assumptions in C2. The aim of this first paper is to propose a technique that is *potentially* suitable for assessing assumptions in C2, to be tested in forthcoming empirical studies. The overall idea is to make use of existing techniques in the area of *risk assessment* to support the assessment of assumptions in C2. Risk assessment is a methodological framework, comprising the four steps of *identification, analysis, description and evaluation*, for determining the nature and extent of the risks associated with an activity, in order to support decision making (Aven et. al, 2014; ISO 31000, 2009; IEC/FDIS 31010, 2009; Lin et. al., 2015; Rausand, 2011). However, even though the existing techniques in the area of risk assessment are designed to be functional in a wide range of situations, they are not specifically designed for assessing assumptions in the context of C2. To be useful for this purpose the proposed technique has to meet the specific characteristics of C2. Thus, the question for this paper is:

How should a technique be designed to be appropriate for assessing assumptions in C2?

The paper is structured as follows: In the next section I will discuss the relations between assumptions, risks and risk assessment. Then I will present the methodological framework of design logic, which has been used in this paper to propose a potentially suitable technique. Thereafter the analysis and results are presented and, finally, I will discuss the results and future work.

Assumptions, risks and risk assessment

As stated above, an assumption in the context of C2 is an *uncertain belief* that something is in a certain way. Thus, because there is a possibility that the assumptions being made are invalid, and that this may have negative consequences, an assumption represents a *risk* (Dewar, 2002). This view, to look upon assumptions as a form of risk, is not unique for Dewar or this paper. The same view can be found also in NATO's planning directive COPD (NATO, 2013) and in the Swedish planning directive SPL (Försvarsmakten, 2015). For example, in COPD it is stated that "each assumption needs to have a risk evaluation" (NATO, 2013: 4-47).

So, what is a risk? One answer to this question is that a risk is *a mental construction about a possible future event* (IRGC, 2005; OECD, 2003; Renn, 2008; 2009; Dean, 2010; Ewald,

1991). According to this view risks are not real phenomena, but more or less well-founded estimations about possible future events originated in the human mind. What is considered to be a risk may therefore vary between different people and between different cultures - or as Renn (2009: 21) puts it: "What counts as a risk to someone may be an act of God, or even an opportunity, for someone else".

There exist many different definitions of risk in the literature (Aven & Renn, 2009a; Aven & Renn, 2010; Aven, 2010; 2012; Rausand, 2011). A traditional definition is: "The possibility that something unpleasant or unwelcome will happen" (Oxford English Dictionary, 2015; see also MacCrimmon & Wehrung, 1986). A similar definition is stated by Rosa: "Risk is a situation or event where something of human value (including humans themselves) has been put at stake and where the outcome is uncertain" (Rosa, 1998: 28). A variation of this definition is found in Aven & Renn (2009a: 6): "Risk refers to uncertainty about and severity of the events and consequences (or outcomes) of an activity with respect to something that human's value". Common to all these definitions is the notion that risk is:

- a possible future event,
- with severe consequences,
- to something that human value.

Thus, in accordance with the reasoning above, in this paper a risk is seen as *a more or less well-founded estimation originated in the human mind, about a possible future event with severe consequences to something that humans value*. This definition also includes assumptions made in the context of C2.

Because of the fact that an assumption in planning and execution of military missions can be considered to be a risk, the assumptions should also be treated as risks, i.e. assumptions as well as other risks in C2 need to be assessed *systematically*. This is important, because any flaw in the assessment process may have severe consequences for the ability to achieve the objectives of a mission. To do this assessment some kind of technique is needed. Here the literature in the area of risk assessment provides us with a variety of different alternatives, for example "Failure Mode and Effect Analysis" (FMEA), "Hazard and Operability" (HAZOP), "Risk Breakdown Matrix" (RBM), "Strengths Weaknesses, Opportunities and Threats" (SWOT), "Structured What-if Analysis" (SWIFT) and many more. As mentioned above, the idea in this paper is to make use of some of the techniques in this area to propose a technique that is *potentially* suitable for assessing assumptions in C2. To do this I utilized the methodological framework of *design logic*.

THE FRAMEWORK OF DESIGN LOGIC

The framework of design logic is described by Brehmer (2013) and Tehler & Brehmer (2013) as a principal tool and a structured framework comprising a design hierarchy of five analytical levels: *purpose, design criteria, function, general processes and form* (figure

2). This five level framework is inspired by Rasmussen's (1985) abstraction hierarchy for Work Domain Analysis (WDA) (Rasmussen, 1985; Naikar, 2013; Reising, 2000; Andersen, 2003), but is used here to construct and propose artefacts (Brehmer, 2013; Tehler & Brehmer, 2013). An artefact is a man-made object, like for example a chair or a computer, but also more soft objects like a procedure, a method or a work schedule (Brehmer, 2013; Simon, 1996; Vicente, 2006). Each level of analysis in the design hierarchy provides an answer to a specific question regarding an artefact.

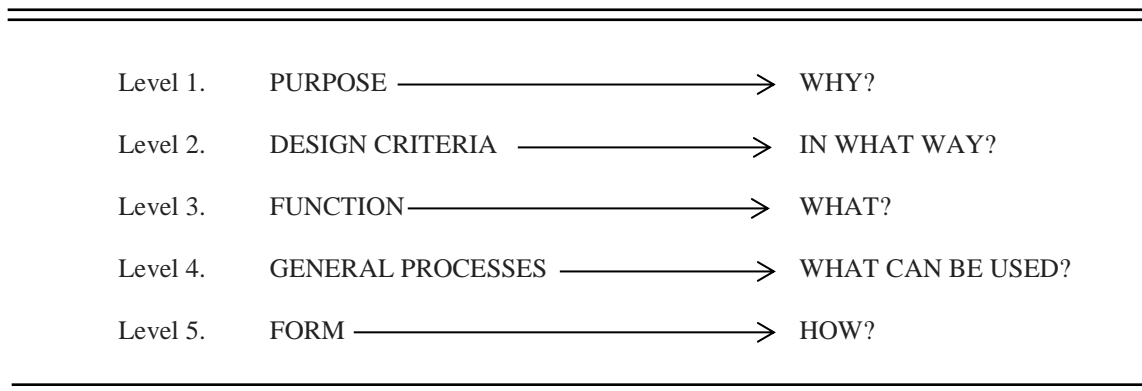


Figure 2. The five level design hierarchy

The highest level in this design hierarchy is the level of *purpose*. A description of an artefact at this level answers the question of 'Why?' the artifact exists or 'Why?' it should be constructed. The next level is the level of *design criteria* and a description of an artefact at this level answers the question 'In what way?' should the purpose be achieved. The design criteria are an expression of the demands and external constraints placed on the artifact (Brehmer, 2013; Tehler & Brehmer, 2013). The third level is the level of *function*. A description of an artefact at this level answers the question of 'What?' the artefact must be able to do to achieve the purpose. The fourth level is the level of *general processes*. This level answers the question of 'What can be used?' to construct the artefact. The last level in the design hierarchy is the level of *form*. This level answers the question of 'How?' the specific artifact fulfills the functions, the design criteria and the purpose. It is at this level that you can find a description and the existence of the concrete artefact. Note that it is sometimes possible to fulfill the functions, design criteria and purpose by different forms (Brehmer, 2013; Tehler & Brehmer, 2013).

An example may clarify the content of the design hierarchy³: Suppose that you want to design some sort of vehicle that can transfer you from place A to place B. Thus, to transfer you from place A to place B is the *purpose* of the artifact. Maybe you place certain requirements on the design, for example that the vehicle should: i) take you from place A to place

³ This example is inspired by Brehmer (2013).

B faster than a horse with a carriage, ii) be less strenuous than riding a bike, and iii) roll on wheels. These requirements represent the *design criteria*. In order to achieve the purpose the construction must fulfill at least two functions: There must be a system for propulsion and a system for changing direction. These are the two basic *functions* needed to fulfill the purpose. From engineering and from physics knowledge can be gathered, which can be useful in the design process to realize these functions. This represents the *general processes*. And finally, at the level of *form* perhaps this is the result of your design efforts, i.e. your design proposition (picture 1):



Picture 1. A car.

In this example the two basic functions (the system for propulsion and the system for changing direction) are realized in the form of a *petrol engine* and a *steering system*, placed in what is known as a car. An alternative could be to realize the functions in some other form and then place them in another kind of vehicle, for example a motorcycle. The next step in the design process is then to evaluate the construction or design proposition, in order to see if the artefact fulfills the design criteria and the purpose.

Because of the fact that the design logic is a general framework, it can be used to construct and propose all kinds of artefacts. In this paper it is used as a tool to propose a technique that is potentially suitable for assessing assumptions in C2.

The use of the design logic framework in this paper has been an iterative process, up and down the different analytical levels in the design hierarchy. In an early stage of the process the purpose for the technique (the artefact) was stated. Then the design criteria's and the functions were specified. Alongside these parts of the process, and to get more knowledge about existing techniques, a literature review was conducted in the area of risk assessment. Finally, at the level of form, one potentially suitable technique to fulfill the functions, design criteria and the purpose was suggested. The outcome from this process is presented next, in the analysis and result section.

ANALYSIS AND RESULTS

The presentation in the result section follows the five analytical levels in the design hierarchy, from top to bottom. Hence, first the purpose of a technique for assessment of assumptions is specified.

Level 1: Specifying the purpose

As stated above, the level of purpose in the design hierarchy describes 'Why' the artifact exists or 'Why' it should be constructed. According to Aven et. al. (2014: 3) the general purpose of risk assessment is to determine "the nature and the extent of the risk associated with an activity". It is possible to use the same reasoning for a technique for assessment of assumptions in C2, i.e. the purpose is to *determine the nature and the extent of the risk associated with an assumption*.

In this paper "determine the nature and the extent" constitutes the process that leads to a statement by a decision maker about *which* assumption to follow up and *if* action has to be taken regarding the assumptions being made (see previous figure 1).

Level 2: Specifying the design criteria

The design criteria are an expression of the demands placed on an artifact. A primary characteristic of C2 comes from the fact that C2 is a so called dynamic decision task (Brehmer, 2000; 2013; Waldenström, 2011). Dynamic decision tasks are decision making under a special set of circumstances:

- They require a **series of decisions**
- The decisions are **dependent of each other**; current decisions constrain future decisions and are constrained by earlier decisions
- The surrounding **environment changes**, both autonomously and as a consequence of the decision makers' actions
- The decisions have to be made in **real time**

These four characteristics impose a number of demands on a technique for assessment of assumptions. These demands have resulted in four criteria, which entail that to be useful in the context of C2 the assessment technique must be possible to use: I) without access to statistical data based on frequencies; II) without assistance from external experts; III) under time pressure and IV) without already developed plans. These four design criteria will now be further described.

Criteria I – Without access to statistical data based on frequencies

Assumptions in the context of C2 are often made about unique phenomenon's, within a unique course of event. Because of the uniqueness of the situation it may be hard or even impossible to get relevant data about frequencies, and therefore also to calculate objective and/or true probabilities based on those data. For example, think of a C2 staff that in a

specific situation has built their plan on an assumption about the capacity and/or intention of an adversary. In this kind of situation it might be impossible to get relevant data, based on historical frequencies about this assumption, for probability calculation.

The difficulty of using statistical data in this type of situation is raised by Aven et. al. (2014), Aven & Renn (2009a; 2009b; 2010) and by Rausand (2011). They mean that, because of the fact that there typically is no historical data available for statistical analysis in this type of situation, it is not meaningful to talk about probabilities based on frequencies in such situations. Here we follow this reasoning, and thus, a technique for handling assumptions in C2 must be possible to use without access to statistical data based on frequencies.

Criteria II – Without assistance from external experts

Assessment of assumptions in C2 needs to be implemented within the regular staff work. It is therefore not appropriate to use a technique that requires participation of external experts. The reason for this is primarily the time factor. On the other hand, if time permits it is of course possible to consult external experts, but the technology should not assume such participation.

Criteria III – Under time pressure

One of the fundamental characteristics of a dynamic decision task is time pressure (Brehmer, 2000; 2013). As a consequence, a technique used for assessment of assumptions should not be time consuming. The exact time constraints are difficult to determine, as this may vary between different situations and different events in the same situation, but the technique must allow a relatively rapid assessment process.

Criteria IV – Without already developed plans

To be suitable, a technique for assessment of assumptions in C2 must be possible to use during the planning process. This means that the technique shall not require a fully developed plan for the assessment to be feasible. The argument for this is also to be found in the fact that C2 is a dynamic decision task, which means that there is probably not room for waiting until the plan is fully developed before beginning the assessment of the underlying assumptions.

Level 3: Specifying the functions

The level of function in the design hierarchy describes 'What' the artefact must be able to do to achieve the purpose (Brehmer, 2013; Tehler & Brehmer, 2013). To fulfill the purpose a technique for assessment of assumptions requires four functions. These functions are the same as the basic components or steps in the risk assessment process⁴ (Aven et. al., 2014; Rausand, 2011) – *Risk identification, Risk analysis, Risk description and Risk evaluation* (figure 3).

⁴ In some descriptions of the risk assessment process the component of "risk description" is included in the steps of "risk analysis" or "risk evaluation", see for example Rausand, 2011: 118. However, in this paper I will keep them apart.

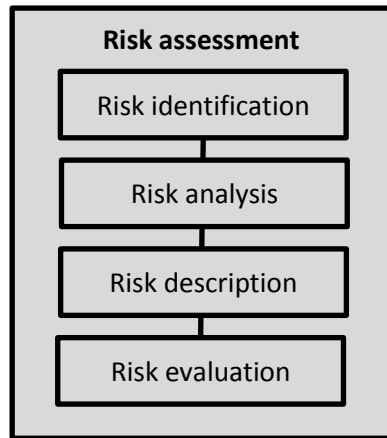


Figure 3. The content of risk assessment

Function I – Identification

The first thing that must be attained in order to assess assumptions is to sort out the assumptions being made from the other planning information. The technique thus needs to contain a function for identification. The product from this function is a list of identified assumptions.

Function II – Analysis

When the assumptions have been identified, they must be analyzed. The purpose of this function is to develop an understanding of the nature of the risk that the assumptions represent and to determine the risk level (IEC/FDIS 31010, 2009; ISO 31000, 2009).

The function of analysis can be divided into three sub-classes: *cause analysis*, *consequence analysis* and *probability analysis* (Aven et. al., 2014). Cause analysis is about establishing causality, i.e. to answer the question: what are the causes and sources of the risk and which assets worthy of protection will be affected by the risk? (Aven et. al., 2014). The consequence analysis answers the question: How severe are the consequences if the risky event occurs? The probability analysis answers the question: What is the likelihood that the risky event occurs? Thus, to be suitable for assessment of assumptions the technique must contain a function for analysis of identified assumptions. The product from this function is descriptions and values from the cause analysis, consequence analysis and probability analysis.

Function III – Description

The results from the risk analysis are presented in a risk description- also called “risk picture” (Aven et. al., 2014; Rausand, 2011). The purpose of the risk description is to communicate the results from the risk analysis to the person who has the responsibility to decide which assumptions to follow up and whether the risk that the assumptions represents are acceptable, or if measures need to be taken to reduce or eliminate this risk. The risk description thus provides the bridge between those who carries out the risk analysis and the decision maker.

Hence, to be suitable for assessment of assumptions in C2 the technique must contain a function for description of the results from the risk analysis. The product from this function is a "picture" of the risk that the assumptions represent.

Function IV – Evaluation

The purpose of the evaluation function is to decide which assumptions to follow up and whether the risk that the assumptions represents are acceptable or if measures need to be taken to reduce or eliminate this risk. The product from this function is a decision regarding these two factors.

Level 4: General processes

The level of general processes in the design hierarchy specifies the areas from which knowledge can be acquired, as well as a description of this knowledge, for the construction of an artifact (Brehmer, 2013; Tehler and Brehmer, 2013).

The table below (Table 1) contains the identified techniques for assessment of risks from the literature review. Thus, the area of risk assessment, with its various techniques, forms the base of knowledge to fulfill the functions, design criteria and purpose. Most of the techniques in table 1 can be found in Cagliano et. al. (2014) and Pritchard (2010).

Table 1. Identified techniques for risk assessment

Nr.	Technique		
1	Brainstorming	27	Sensitivity Analysis
2	Cause and effect diagram or Cause Consequence Analysis (CCA)	28	Strengths Weaknesses, Opportunities, and Threats (SWOT)
3	Change Analysis (ChA)	29	SWIFT Analysis
4	Checklist	30	What-if Analysis
5	Decision Tree Analysis	31	5 Whys Technique
6	Delphi	32	Planning meetings
7	Event and Causal Factor Charting (ECFCh)	33	Risk practice methodology
8	Event Tree Analysis (ETA)	34	Document review
9	Expected Monetary Value (EMV)	35	Analogy comparisons
10	Expert Judgement	36	Plan evaluation
11	Fault Tree Analysis (FTA)	37	Crawford Slip Method (CSM)
12	Failure Mode and Effect Analysis (FMEA)	38	Root Cause Identification and Analysis (RCA)
13	Failure Mode and Effect Criticality Analysis (FMECA)	39	Risk Register/Tables
14	Fuzzy Logic	40	Project Templates
15	Hazard and Operability (HAZOP)	41	Assumption Analysis
16	Hazard Review (HR)	42	Decision Analysis – Expected Monetary Value
17	Human Reliability Assessment (HRA)	43	Estimating Relationships
18	Incident Reporting (IR)	44	Network Analysis (Excluding PERT)
19	Interviews	45	Program Evaluation and Review Technique (PERT)
20	Monte Carlo	46	Rating Schemes
21	Pareto Analysis (PA) or ABC analysis	47	Urgency Assessment
22	Preliminary Hazard Analysis (PHA)	48	Data Quality Assessment
23	Risk Breakdown Matrix (RBM)	49	Risk Modeling
24	Risk Breakdown Structure (RBS)	50	Risk Factors
25	Risk Mapping, Risk Matrix, Probability and Impact Matrix	51	Risk Response Matrix
26	Risk Probability and Impact Assessment, Risk Ranking/ Risk Index	52	Risk Review and Audits
		53	Reliability Centered Maintenance (RCM)

The table shows that there exist a whole variety of techniques for assessing risks. The idea in this paper is to use some of these techniques to propose a technique, on the level of form, which is potentially suitable for assessing assumptions in C2.

Level 5: Specifying the functions on the level of form

On this level, the lowest level in the design hierarchy, the various functions are realized in concrete form. As mentioned earlier, there may be many different ways to realize a function on the level of form (Brehmer, 2013; Tehler & Brehmer, 2013).

There are two principally different ways to handle the various techniques in table 1. One way is to start with the different techniques in table 1 and then, one by one, sort out those techniques which in their original form have the potential to fulfill the functions, the design criteria and the purpose. However, the literature in the area of risk assessment doesn't describe each technique in a way that makes this matching and sort out possible, i.e. the descriptions in the literature are not specific enough in relation to the functions and the design criteria for C2. The other way is instead to start with the functions and then try to find techniques that have the potential to fulfill each function and design criteria. This approach makes it possible to combine contents from different techniques and thereby to customize a technique that is potentially suitable for assessing assumptions in C2, based on multiple techniques from table 1. In this paper I have used the later approach.

The form of the identification function

A common form for identification within the area of risk assessment is by using some sort of, more or less, systematic brainstorming. Two techniques in table 1 that uses this approach, and which have the potential to meet the specific design criteria for assessing assumptions in C2, are HAZOP (No 15) and SWIFT (No 29). These techniques are possible to use without access to statistical data based on frequencies; without assistance from external experts; under time pressure and without already developed plans. HAZOP is a qualitative technique for identification of hazards and deviations in different types of systems, by using *guidewords* related to the system in question. (Rausand, 2011; IEC/FDIS 31010, 2009). Under the guidance of an appointed "HAZOP-leader", within the risk assessment team, the other participants in the team responds to questions related to the guidewords, regarding what can go wrong in the system that is in focus. To stay in control of the process the results are inserted into a worksheet. SWIFT is a similar technique as HAZOP, but instead of using guidewords SWIFT uses "what-if" questions to identify risks and possible hazardous events, based on a checklist, for example questions like "What-if a fire occurs in the system?" (Rausand, 2011). Also this technique uses a "worksheet" to keep track of the process (Rausand, 2011).

The identification of assumptions in C2 is about sorting out those things in the planning process that is considered to *have been, are* and, which is the focus in this paper, *will be* in a certain way. One way to do this, based on the two techniques above, is by using the guidewords "will be" and its negation "will not be" and then formulate these guidewords into questions, e.g. "According to the plan, what will be in a certain way?" and "According to the plan, what will not be in a certain way?". The answers to these questions constitute

assumptions about future conditions, which can be more or less important for the possibility to reach the goals of the mission, for example: “according to the plan, the bridge over river X will be passable on Friday at 3 p.m.” or “according to the plan, the enemy units located in the south will not be rebounded within the next 72 hours”.

One possible way to structure the identification phase is by using the seven factors in the so called “possibility space”: *mission, possibility of action by the enemy, own resources, time factor, terrain, ROE and doctrine* (Brehmer, 2013). If the guidewords and questions above are combined with these factors the following worksheet is obtained (table 2).

Table 2. Worksheet for identification of assumptions

	According to the plan, what <u>will be</u> in a certain way?	According to the plan, what <u>will not be</u> in a certain way?
Mission		
Enemy		
Own resources		
Time factor		
Terrain		
ROE		
Doctrine		

This worksheet is possible to use in the identification phase by the team within the staff that has the responsibility to assess assumptions, preferably the same team that has the responsibility to assess other risks within the planning process. The identified assumptions then need to be analyzed.

The form of the analysis function

In accordance with previous discussion, the function of analysis is divided into three subclasses: *cause analysis, consequence analysis* and *probability analysis* (Aven et. al., 2014). To sort out the important assumptions, i.e. the so-called load-bearing assumptions (Dewar, 2002), from the less important it is probably best to start with the consequence analysis. A consequence analysis should provide information about the effects if an assumption is incorrect, or what effect that could occur if an assumption falls. Thus, the consequence analysis should inform the analyst about both *what* can happen and the *severity* of this occurrence.

One technique in table 1 that can be used to carry out the consequence analysis, and which have the potential to meet the design criteria, is Event tree analysis (No 8) (Aven et. al., 2014; Rausand, 2011). In an Event tree analysis a “tree structure” is used to model a possible course of events on the basis that an identified risky event has occurred - in this case that an identified assumption is wrong or has fallen. This technique can be used together with a so called Fault tree analysis (No 11), by which the *causes* of an event are analyzed (Rausand, 2011). If these two techniques are combined a “Bow-tie diagram” is obtained (figure 4).

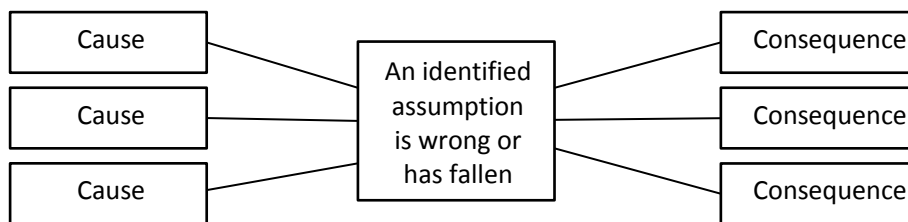


Figure 4. Bow-tie diagram for analysis of identified assumptions

In this combined technique the idea is to reason, in a structured manner, about what causes and consequences a wrong or fallen assumption has on the plan and the possibility to reach the goals of the mission. However, this kind of analysis doesn't tell us anything about the likelihood of the event. To get this kind information some sort of probability analysis has to be conducted. One purpose with the probability analysis is to make it possible to prioritize between different identified assumptions with equally serious consequences, so that the one with the highest probability to occur is considered more important to handle than the one with the lower probability.

Traditional probability analysis can be either quantitative, e.g. built on frequencies, or qualitative. In accordance with design criteria I above, regarding the difficulties to get relevant data about frequencies, the focus in this paper is on qualitative probability analysis.

One possible way to qualitatively determine the probability for a risk to occur, in this case if an assumption is wrong or will fall, is by using so called "subjective probabilities" (Aven et. al., 2014; Flage et. al., 2014). A subjective probability is an expression by a person based on that person's background knowledge about the risk in focus. Thus, subjective probabilities are probabilities in the light of current knowledge (Aven et. al., 2014). These probabilities can be expressed by using different types of scales, for example "low", "medium", "high" or some sort of interval, for example "higher than 70%", "between 50-70%", "lower than 50%".

The combination of analysis regarding causes, consequences and probabilities are intended to give values on the severity of a wrong or fallen assumption. In the next step these analysis have to be communicated to a decision maker. This is done by some form of description (Aven et. al., 2014).

The form of the description function

The analysis of identified assumptions can be described in a number of different forms; for example by a verbal description, a text based description or by using some form of picture. A common form built on the analysis of consequences and probabilities, and which have the potential to meet the design criteria, is to use some sort of "risk matrix" (figure 5).

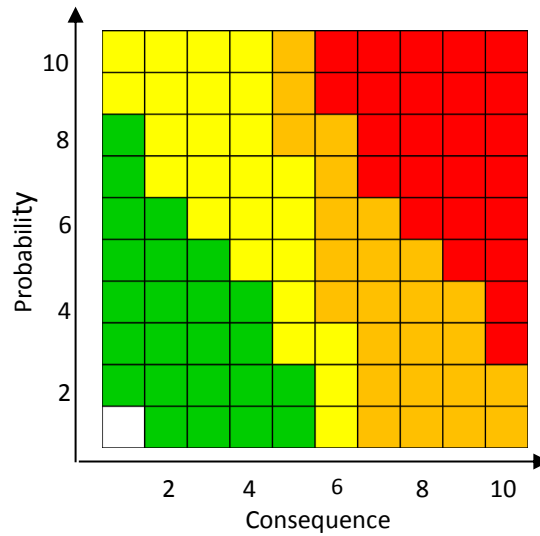


Figure 5. A risk matrix

In this form of description values from the analysis are put into the matrix regarding both consequences and probabilities. Then a color in the matrix shows the level of risk (white = no risk, green = low risk, yellow = increased risk, orange = high risk, red = very high risk). This form of single-valued two dimensional probability based approach is used for risk description by the Swedish Armed Forces (Försvarsmakten, 2009). However, this traditional single-valued probability based approach has been criticized for being too narrow in sight, especially in situations where it is difficult to determine probabilities (Bjerga & Aven, 2015; Veland & Aven, 2015; Aven, 2013) - as for example to calculate the probability for a terrorist attack in a country where such events are rare (Aven & Renn, 2009a, 2009b, 2010). In an attempt to obtain a more adequate risk description for this kind of situations a broader risk perspective has been proposed, using the variable of *background knowledge* combined with *strength* in that background knowledge, (Bjerga & Aven, 2015; Veland & Aven, 2015; Aven, 2013). According to Bjerga & Aven (2015), the difficulties to determine probabilities in some situations, as for example in C2, implies that the traditional way to describe risk, by specifying consequences and single-valued probabilities, must be complemented with background knowledge on which the consequences and probabilities are based. Bjerga & Aven (2015:76) argues that:

“...the probability cannot be viewed in isolation from the knowledge it is based on. The decision analysis may, for example, contrast two cases, one where the strength of knowledge is strong and one where it is weak, and the conclusion on which alternative to choose should take this information into account. This is in particular important for the deep uncertainty case, where, as mentioned before, probabilities are hard to justify. It could be directly misleading and potentially dangerous to use conventional decision analysis when the knowledge base is so poor.”

Thus, this view implies that the background knowledge and its strength should affect decision making, in a way that if the background knowledge is poor the risk should be considered higher than if the knowledge is strong (Bjerga & Aven, 2015).

One way to illustrate this on the level of form is to complement the risk matrix with values also about the strength in the background knowledge (figure 6).

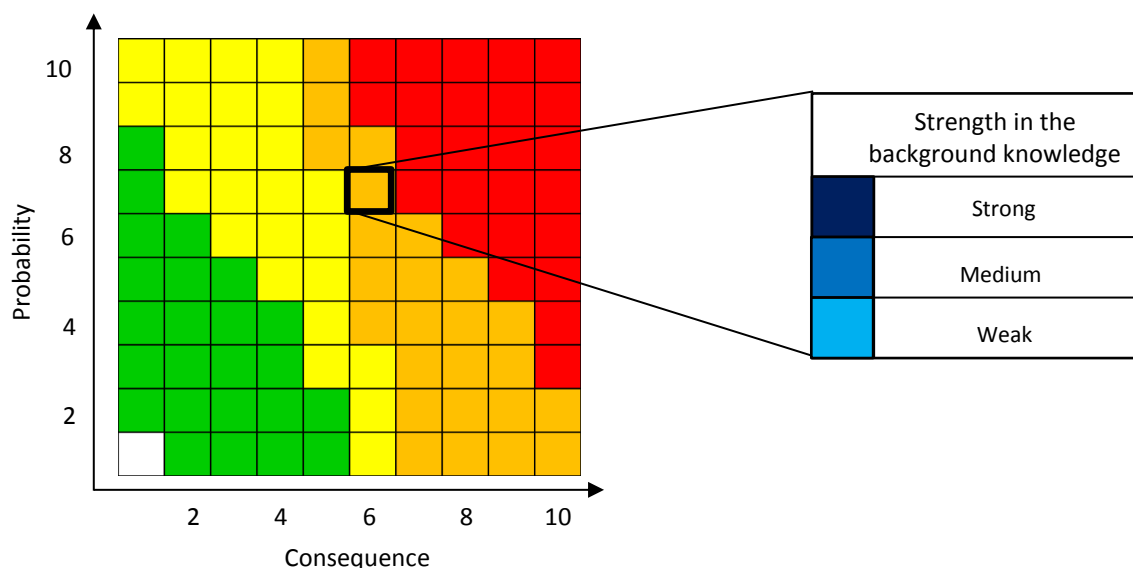


Figure 6. A risk matrix complemented with the strength in the background knowledge

The complement in the risk matrix (figure 6) shall be understood in the following way: Based on the combination of consequence and probability the level of risk is assessed to be high (orange color in the matrix), regarding for example a falling assumption. In this example the strength in the background knowledge of this assessment can either be “strong” (dark blue), “medium” (blue) or “weak” (light blue). The idea is that a high level of risk (orange) that is built on a strong background knowledge (dark blue) is more reliable than a high level of risk (orange) that is built on a weak background knowledge (light blue). This complement constitutes an additional dimension, alongside the consequences and probabilities, for a description of the risk that an assumption represent. These different values are important inputs for the evaluation function.

The form of the evaluation function

Risk evaluation is about reaching a standpoint regarding if a described risk is acceptable or if some kind of action has to be taken to minimize or eliminate the risk. The most common form for risk evaluation is to compare the risk description against some kind of criteria for what constitutes an acceptable level of risk (Aven et. al., 2014; Rausand, 2011). A criterion of this kind is an expression of an organization’s values, objectives, resources and

risk appetite (Public Safety Canada, 2012). Thus, this criterion can vary between different organizations and situations. In this case, the evaluation is about reaching a standpoint regarding if an assumption should be followed up or not.

This form of evaluation, to compare the risk that an assumption represents, against some kind of criteria will probably meet the design criteria, i.e. it's possible to use without access to statistical data based on frequencies; it's possible to use without assistance from external experts; it's possible to use under time pressure and it's possible to use without already developed plans.

Summary of the results from the analysis

The analysis above has resulted in a design logic scheme and a design proposition regarding the four identified functions.

The design logical scheme

If the reasoning in the analysis above, regarding the five levels in the design hierarchy, is put into a design logical scheme the following figure is obtained (figure 7).

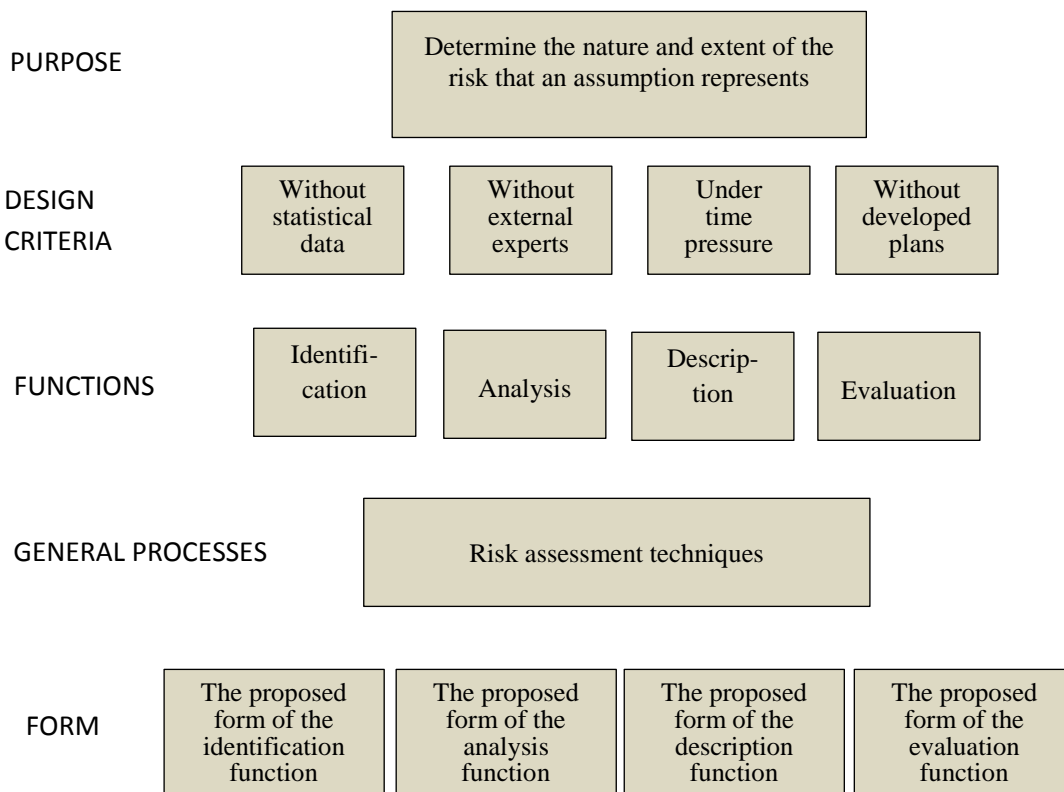


Figure 7. A design logical scheme regarding a technique for assessment of assumptions in C2

This figure summarizes the reasoning regarding the purpose, design criteria, functions, general processes and form for a proposed technique for assessment of assumptions in C2.

The design proposition

The proposed forms of the four functions are summarized in the following design proposition (table 3):

Table 3. The design proposition on the level of form

Function	Design proposition
Identification	To identify assumptions use a combination of HAZOP and SWIFT together with the factors in the so called "possibility space" to form a worksheet for identification.
Analysis	To analyze the consequences and causes of a wrong or fallen assumption use a combination of Event tree analysis and Fault tree analysis in a Bow-tie diagram. To determine the possibility that an assumption is wrong or will fall use subjective probabilities.
Description	To describe the analysis of the assumptions use a combination of values on the factors of consequence and probability together with the strength in the background knowledge regarding those factors.
Evaluation	To determine which assumptions to follow up and if action has to be taken regarding the assumptions use a criterion for what constitutes an acceptable level of risk.

The table shows that each of the functions has their own form. Together these forms represent the design proposition for a technique that is *potentially* suitable for assessing assumptions in C2.

DISCUSSION AND FUTURE WORK

The aim of this paper has been to propose a technique that is *potentially* suitable for assessing assumptions in C2, to be tested in forthcoming empirical studies. The question asked was:

How should a technique be designed to be appropriate for assessing assumptions in C2?

The overall answer to this question is: to be appropriate for assessing assumptions in C2 the technique has to fulfill the four identified functions, the four design criteria and the purpose (see figure 7). The results of this paper are a design logical scheme and a design proposition, i.e. a hypothesis on the level of form, for each of the four identified functions, based on different techniques from the area of risk assessment. The results indicate a pos-

sibility to support the assessment of assumptions by using this approach and thereby the possibility to enhance the ability of military staffs to make timely re-planning if important assumptions are wrong or if they fall. The results also show the possibility to incorporate assumptions into the theoretical framework of risk. The use of existing and established techniques from this area provides an opportunity for a connection to the extensive research and existing knowledge in this field, about the characteristics of different techniques, compared to the alternative to develop completely new techniques for the assessment of assumptions. This approach also implies the possibility to subsume the assessment of assumptions into the general risk assessment process in C2, so that no parallel processes need to be introduced in this area.

Further, the results show that it is possible to use the framework of design logic for the purpose to propose a technique of this kind. This in turn demonstrates the strength and the generality of the design logical framework. One of the weaknesses in this study is of course the absence of empirically grounded results, i.e. at present we don't know if the proposed technique is appropriate or not. Two other weaknesses are methodological and points to the likelihood of missed relevant design criteria and missed alternative techniques.

Therefore, the next step in this work is to test the proposed form for each of the four functions, to see if they are functional and fulfill the design criteria. This is probably best accomplished through experimental studies, where the proposed designs are compared to other forms and with a distinct operationalization of the design criteria. To accomplish this I will probably start with the function of *description*, because of its important role as the bridge between the risk analyst and the decision maker within the dynamic context of C2 in the complex connected battlespace.

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