Coupling Models of Complexity and Models of Cognition in a Systems Design Process

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ABSTRACT
Work can be complex for several reasons, and various kinds of complexity put different demands on human behaviour and problem solving. New types of complex systems are introduced at increasing rates, both for professional work and in everyday life. We argue that there is a need for a tighter coupling between the characteristics of complexity and the characteristics of cognition in systems design for complex work. This paper outlines a proposal for such a framework. The framework couples existing models of complexity with well-known models of human skill and cognitive styles to provide a tool for capturing system and personnel needs in systems design processes. It relies on the identification of sources of complexity in the work domain, and can be used in a method-independent fashion to guide predictions on cognitive demands. The development of a military command and control support system for helicopter units is used to exemplify the use of the proposed framework.

Keywords
Complexity, cognition, systems design

INTRODUCTION
Today's systems are becoming increasingly complex. The strive for efficiency and the need to handle more complicated problems strain human capabilities. Moreover, human roles are shifting towards supervisory and cognitively demanding tasks. Therefore, learning and using systems efficiently is getting increasingly crucial. To support people in their roles as system designers and as system users, it is important to incorporate and couple models of complexity and models of cognition in the systems design process.

Existing methods, aiming at bringing forth solutions that can handle complex work, usually describe and break down the concepts of complexity and cognition. One of the most elaborate approaches is cognitive work analysis, CWA (Vicente, 1999). However, even though CWA decomposes complexity in different dimensions, these sub-parts are not explicitly coupled to cognitive demands. Such a coupling could support assigning staff or teams to different roles depending on the nature of the sources of complexity identified in the system and its domain. Furthermore, it could help identify where complexity demands people with expertise. Also, this coupling could direct system design decisions based on how various types of complex work require different types of cognitive support. Crossland and colleagues showed how cognitive style and task complexity relate to effectiveness when agents use a geographical information system (Crossland, Herschel, Perkins & Scudder, 2000). However, they did not discuss any special characteristics of complexity other than two levels of general task complexity concerning the number of items under consideration.

This paper outlines a proposal for a framework for coupling characteristics of complexity and certain characteristics of cognition to support systems design. To capture cognitive aspects relevant to the assignment of staff and the demands on expertise we use models of skill levels and cognitive style. The model of skill (Dreyfus & Dreyfus, 1986) covers how actors pass at least five stages of skill improvement and what characterizes these different stages. Related to skill are cognitive modes (Norman, 1993). They concern the differences between reactive and reflective cognition—subconscious pattern recognition and analytical reasoning. Cognitive style (Sternberg & Grigorenko, 1997) is a means to characterize how different humans behave and how they approach various problem situations.

In this paper, we first introduce the concept of complexity and ways to characterize complex systems. We then describe the cognitive models: skill and cognitive style. Next, we propose a framework that couples the models of complexity to the models of cognition and give examples of how differences in complexity impose different cognitive demands. Finally, we describe a practical application of the framework concerning the development of a military command and control support system for helicopter operations. A discussion concludes the report.

The framework is an outline towards a practical application of existing well-known models. Thus, research and experimental work still needs to be performed to investigate the constituents of the framework.

MODELS OF COMPLEXITY

The concept of complexity has many interpretations (Bainbridge, Lenior & van der Schaaf, 1993). According to Leplat (1988), complexity is coupled to the operator. A task may be complex for one person, but simple for another. Increasing the operator's skill may reduce task complexity for her: "task complexity is not the same at the beginning and at the end of learning" (p. 107).

Woods (1988) elaborates further and sees a triadic composition of complexity:

1. *World:* Different characteristics of the domain will make some things harder than others.
2. *Representation:* The way a problem is represented affects how it can be solved (Woods, 1995): "… solving a problem simply means representing it so as to make the solution transparent" (Simon, 1996, p. 132).
3. *Agent:* Complexity also depends on the problem-solving capabilities of the agent involved in a situation.

For our purposes, we shall concentrate on aspects of complexity that pertain to the world and the tasks in the world. We shall address properties of the agent when we discuss models of cognition. For representation issues, see Woods (draft; 1995).

Woods (1988) uses four dimensions to characterize complexity arising from the *world* or domain:

- *Dynamism:* To what extent can the system change states without intervention from the user? To what extent can the nature of the problem change over time?
- *Interconnecting parts:* The number of parts and the extensiveness of interconnections between the parts or variables. To what extent can a given problem be due to multiple potential causes and to what extent can it have multiple potential consequences? To what extent are there competing goals and to what extent can multiple on-going tasks have different time spans?
- *Uncertainty:* To what extent can the data about the system be erroneous, incomplete, or ambiguous—how predictable are future states?
- *Risk:* What is at stake? How serious are consequences of users' decisions?

Leplat (1988) describes three temporal factors of complexity that are not mainly characteristics of the world, but rather characteristics of the tasks involved, and therefore related to the agent. From one point of view, Woods' four dimensions may subsume these sources of complexity. However, they explicitly capture crucial aspects of complexity, and for our purpose that is more important than finding a pure taxonomy:

- *Time pressure:* Users must handle situations where the rate of input or amount of simultaneous data exceeds their ability to gain enough information (data overload). They may filter data, queue tasks or, if worst comes to worst, abandon the tasks (cf. the dynamism and parts dimensions).
- *Interruptions:* Many straightforward tasks can be hard to continue if they get interrupted. An interruption may be another more urgent task or a disturbance in the environment (cf. the dynamism and parts dimensions).
- *Feedback delays:* When feedback is lacking or delayed, operators must rely on feedforward control (Hollnagel, 2003)—that is, open-loop or prospective control. Depending on the nature of the feedback problems and the operator's mental models of the situation, this approach may be more or less opportunistic. If the user has a solid knowledge of the emerging situation, she may be able to carry out successful actions without feedback. However, in many cases it would be hard to know the current state of the system (cf. the uncertainty dimension).

Bainbridge et al. (1993) add the social dimension:

- *Dependencies of other workers:* Tasks that to a high degree must be carried out in a group or that have parts that other workers need to be involved in or aware of, put special demands on involved practitioners. Examples include communication, synchronization, externalization and interpretation of problems, and other social matters. Human involvement and behaviour naturally contribute to overall system complexity, making this source of complexity a part of all others.

All these approaches to characterizing the components of complexity overlap, and the dependencies between the parts are extensive. Therefore, it is important to realize that two or more sources of complexity together can produce new characteristics of a system. Our aim is to build tools that can aid a design process, not to find "the true" models. Therefore, we must exercise judgement and reflection when combining dimensions of complexity. Using the complexity dimensions as a frame of reference for analysing the system supports the design process by enabling a better understanding of the problem setting and by generating ideas for solutions. Nevertheless, to further support this kind of hypothesis generation in a design process, we need to couple the complexity dimensions to models of variation of cognitive processes.

MODELS OF COGNITION

In a design process, it is valuable to get hints on where complexity imposes skill requirements and what type of behaviour or problems-solving approaches it favours. To this end, we have chosen to relate to the concept of complexity to two aspects of cognition: *levels of skill* and *cognitive style*.

Levels of Skill

Dreyfus and Dreyfus (1986) explain that a person passes at least five stages of skill improvement. They propose the following model of skill:

1. *Novice:* This stage is described as "information processing" since it involves learning (and later identifying) certain objectively defined context-free elements that are coupled with equally context-free rules. Novices can only relate these elements to the rules they have learned. They cannot prioritize, formulate goals or plan, or conduct other context-dependent actions.
2. *Advanced beginner:* When a novice has experienced real situations and can cope with them to a considerable degree, she can begin to take more of the context-free facts into account and use more of the context-free rules. Beginners start to recognize certain elements by experience, thus making them less context-free.
3. *Competent:* A competent person can begin to make plans, and can discern that some elements in a situation are more important than others. This step is fundamental, since people cannot continue to choose deliberately from a growing collection of context-free elements and rules, without the ability to filter and take shortcuts. Competent persons are also more involved in their actions, since they are not merely following prescribed rules.
4. *Proficient:* A proficient person identifies important features of a situation and disregard unimportant ones automatically. The person often operates in a reactive manner, based on experience of similar situations. However, she will still analytically assess the important elements to arrive at appropriate actions. Intuitive understanding is followed by less involved decision making.
5. *Expert:* Understanding, planning, and decision-making all come naturally and subconsciously to an expert. Experts act apparently effortless and without deliberation; they do what normally works—they *experience* things rather than *analyze* them. Even though experts operate in a highly reactive manner, they are capable of deliberate reflection when time admits. In deliberate reflection, experts seek to view things from another perspective, to avoid being caught on a "reactive road" into tunnel vision.

In essence, Dreyfus and Dreyfus (1986) stress the fundamental limitations of regarding human skill as mainly analytical and context-free information processing. Instead, they show that skilled humans largely perform in situational, involved and holistic ways.

Closely related to levels of skill, are Norman's (1993) cognitive modes. He defines two modes of cognition:

- *Reactive cognition:* This mode is described as automatic and without conscious awareness, similar to the expertise discussed earlier. Patterns are perceived and appropriate actions are carried out without apparent effort. No new ideas come out of reactive cognition.
- *Reflective cognition:* This mode considers concepts, planning and reconsideration in a top-down manner, and is slow and laborious. It is analytical reasoning and exploration of new ideas.

While the coupling between complexity and level of skill mainly guides the selection of roles or the assignment of workers to roles, the coupling of complexity to cognitive modes pertains to system design decisions. One example of such a decision is whether a function should be designed to encourage reactive cognition, or to make the agent slow down and think about alternative approaches.

Cognitive Style

Cognitive style is a means to characterize how different humans behave and how they approach problem situations. Research on cognitive style goes back to the 1940s and covers many different models and approaches. (Riding and Rayner (1998) provide an overview.) Some researchers are sceptical to the usefulness of cognitive style as a basis for systems design (e.g. Huber, 1983). Huber argues that to be useful, the cognitive style assessment instruments must be sharp enough to handle the grand variability of real work situations. Therefore, he believes cognitive style research needs to move "in the direction of relating the predictive validity of particular instruments to particular types of decision situations" (p. 573).

More recently, Sternberg and Grigorenko (1997) argue that there are at least three motivations for cognitive styles:

1. Exploring links between cognition and personality
2. Understanding and improving learning
3. Improving vocational selection and placement

All these motivations are relevant when we deal with complex systems, for example to answer how users go about learning a complex system, or how people with different styles are better or worse suited for various roles in the system.

Sternberg and Grigorenko (1997) propose a broad approach to cognitive styles that covers many aspects of cognition. They call it the *theory of mental self-government* from their assumption that different governmental styles can be seen, to some extent, as reflections of different styles in the mind. We use this model to relate sources of system complexity to cognitive styles because it has been evaluated and found to distinguish several different kinds of cognition. The styles are divided into five main categories of mental self-government (p. 707):

- *Functions:* The *legislative* style is said to portray persons that create and follow their own rules, instead of following existing predefined rules. Persons with an *executive* style, on the other hand, are "doers". They rely on and follow existing methods, and want things to be well defined and structured. Persons of *judicial* style like to analyze, evaluate and judge rules, procedures and ideas.

- *Forms:* Persons of a *monarchic* style, focus on a single task at a time, until it has been completed. The *oligarchic* likes dealing with multiple goals, and parallel activities, although she tends to give equal importance to all of them. A person of *hierarchic* style prioritizes among multiple goals. Persons of *anarchic* style tend to dislike being restricted to particular ways of solving problems, and rather take a random approach with little insight of usefulness.
- *Levels:* A person of *local* style favours specific, precise tasks that involve concrete details, whereas a person of *global* style prefers general problems that require abstract and conceptual thinking. These styles are similar to the analytic–holistic ones (Riding & Rayner, 1998).
- *Scope:* Persons that prefer to work with tasks that allow them to be alone can be described as being of *internal* style, whereas persons that prefer working together with others, fit the *external* style.
- *Leanings:* Persons of *liberal* style allow considerable change to how things are currently approached, and are happy to adopt other people's ideas and methods. Persons of *conservative* style, on the other hand, prefer familiar solutions and when they come up with new ideas, they tend to conform to traditional approaches.

Similar to the coupling between complexity and skill, the coupling to cognitive styles may guide the selection of roles or workers. The latter, however, addresses ways of perceiving the world and approaching problems rather than factual skills and levels of skill. In addition, it is important to realize that a *designer's* cognitive styles—which affect her proposed solutions—may be very different from the styles of the *users* of the future system.

COUPLING THE MODELS

Having discussed different aspects of complexity, agent skill, cognitive modes, and cognitive styles, we shall explore their relationship. Since there are many possible combinations to consider—as depicted in Figure 1—we provide examples based on selected aspects (as highlighted in Figure 1). The aim is to present the idea behind the framework, not to complete all its steps. The resulting model is a two-dimensional matrix of complexity and cognition which we denote the CCM model. We discuss additional cells of the CCM in the application example section.

Time Pressure and Skill

A *beginner* or *novice* would not know what is important in a context and would probably focus on arbitrary or wrong things. A *competent* person can set goals and plan actions according to urgency and is therefore able to handle moderate time pressure. An *expert* works as

Cognitive characteristic		Complexity characteristic							
		Dynamism	Parts	Uncertainty	Risk	Time pressure	Interrupts	Feedback lag	Dependency of others
Level of skill	Novice Beginner Competent Proficient Expert	B, C	B	C	B	A	A	D	C
	Reactive Reflective	A, C		A, C	A, C	A, C	A, C		A, C
Cognitive style	Legislative Executive Judicial				B				
	Monarchic Hierarchic Oligarchic Anarchic		B						
	Local Global	B							
	Internal External								
	Liberal Conservative			A, D		A, D		A, D	

Figure 1: The complexity cognition matrix. The highlighted cells represent issues that are discussed in the report, and the cells marked with letters (that represent the roles in Table 1) are further brought up in the example section.

reactively as possible, and is likely to know what to concentrate on. She works more intuitively and situationally with less need to reflect. However, in situations with very high time pressure, an expert would not get the time for deliberate reflection, even when needed.

Parts and Cognitive Style

An agent of *monarchic* style would not be able to perform well in a system characterized of many parts, variables and interconnections, because of the need to handle multiple goals simultaneously. *Oligarchic* individuals, would accept the multiple goals, and take on several tasks simultaneously. However, competing goals of different urgency would not fit his or her style. A person of *hierarchic* style however, would be ideal both to deal with multiple tasks and to assess the relative importance of the tasks. Even an *anarchic* person, prone to unpredictable approaches, might be successful in tackling the problem of multiple causes and consequences, since she, by definition, tries out untraditional solutions.

Uncertainty and Cognitive Mode

Since *reactive* cognition is characterized by "automatic" responses to patterns or higher-level data, there is an assumption that the set of tasks is thoroughly practiced and experienced. When uncertainty is high, such "reliable" patterns may be rare, making "unpredicted once-in-a-lifetime" situations more frequent. Such situations would surely require *reflective* cognition, because the agent would not have enough experience to enable reactive cognition.

Risk and Cognitive Style

Operators dealing with high-risk systems, where serious consequences may result from actions, need to judge and evaluate procedures before acting. A *judicial* person would be suited for this situation, since she puts a lot of effort on the analysis, rather than the implementation of tasks. An *executive* person's focus on following and mastering existing procedures may be efficient, but can fail if no analysis is conducted whether modifications are needed. A *legislative* person could find viable solutions to approach a risky task, but might face problems if she ignores existing procedures and regulations.

In a situation with both risk and high time pressure, a person of *executive* style may be more suited than one of *judicial* style, since implementing one possible action efficiently may be better than analytically, and more slowly, finding a near-optimal solution.

Interruptions and Cognitive Style

In situations where interruptions are frequent, operators must maintain a general overview of the larger situation rather than tending to details. A person of local style would be less suitable for such a situation, since she is likely to deal with details that require precise executions, and may have problems grasping the bigger picture, involving other tasks and goals. A person of *global* style would handle this situation better, because she likes to conceptualize and see problems on a more general level.

Feedback Lag and Cognitive Style

Operators that do not receive feedback on their actions and thus cannot establish the current state of the system must go beyond existing rules that prescribe what to do in certain situations. A person of *liberal* style would be better suited to handle this problem than would a person of *conservative* style, because the *liberal* is less prone to follow traditional regulations strictly.

Dependency of Others and Cognitive Style

Persons of *internal* style would perform worse than would persons of *external* styles in a situation that requires cooperation with other workers. This could be most notable in a situation where an operator perceives the dependency as unnecessary or ineffective. An *internal* person would be less cooperative than an *external*, leading to a possible degradation of the system performance as a whole.

APPLICATION EXAMPLE

We shall give an example of the intended use of the CCM in a practical application. The example is based on two field trials, where multiple data sources were used to collect and analyse data from a large military exercise involving numerous units. The field trials were a part of the development of a new command and control system for military helicopter units. The example concerns a helicopter unit with the task to transport an airborne ranger battalion from their base to the area of operations some 100 kilometres away.

First, we identify sources of complexity in the helicopter and airborne units' command and control process and grade them according to their severity. Then, we insert these results into the CCM model to generate hypotheses about needs to consider in the design process (see Figure 2). Note that at this stage, the data collected are used for explanatory reasons, not as empirical results (see Morin (2002) for more information on our approach to collect, present and analyze field data).

Identifying Complexity Differences

There are many ways to slice the complexity pie of a command and control system. We used *roles* and *situations* to structure our analysis. In our example, the roles were selected to cover a wide range of areas of responsibility:

A. *Pilot (helicopter unit):* The role of flying and navigating the helicopter.

B. *Company commander (helicopter unit):* The role of commanding and controlling the subordinate helicopter units.

C. *Cargo coordinator (airborne unit):* The role of providing the helicopter unit with the airborne unit's goals and needs, and making clear the constraints and possibilities from the helicopter unit to the airborne unit.

D. *Platoon leader (airborne unit):* The role of carrying out tasks according to the commanding officer's intent.

The *situations* to include in the analysis were chosen from observations during exercises, from earlier task analyses, and from regulations and manuals. Examples of situations are rescue operations, tactical planning, and transport of cargo. For each situation, we constructed a *complexity analysis sheet*, including a table with complexity characteristics in one dimension and roles in the other (see Table 1 and Figure 2 for an example). For each cell of the table, we entered a judgment of the severity of the complexity characteristic with a short motivation (for space reasons Table 1 shows only the rating of severity).

In this example, we examine the situation of *re-planning due to difficult weather conditions and technical problems in large-scale operations***.** If weather conditions make flying too hazardous or if technical breakdowns force helicopters to remain on the ground, the transportation plan may quickly become obsolete. Cargo lists and deadlines have to be reassessed to get the most important equipment and personnel to their destinations. If not resolved, the circumstances will impede the mission of the airborne unit. In the following analysis, it is important to keep in mind that discussions about the complexity characteristics of various roles concern *the specific situation* and not the responsibilities of the roles in general.

Generating Hypotheses

We examine the complexity analysis sheet to explore how to generate hypothesis of future needs. In Figure 1, the cells in the CCM that will be covered in the examples have been marked with the letters of the four roles.

Levels of skill

We investigate how skill level demands *concerning re-planning* may vary for the different roles. We start with the pilot's view.

Most complexity dimensions for the pilot are rated as average (Table 1). This is mainly because re-planning is not of main concern for this role. Furthermore, re-planning for the pilot would most often concern a subset of the overall situation. However, since the pilot's main task of controlling and navigating the helicopter requires continuous and focused attention, the time pressure and interruptions dimensions are rated as very high. There is not a lot of time available for re-planning, especially not for continuous periods. As we mentioned in the discussion of the CCM, handling high time pressure may require skilled operators. When it comes to interruptions, novices or beginners, who rely on reflective cognition, may have problems sustaining a task when they are being constantly interrupted: even if they are able to conduct the task uninterrupted. To summarize, the pilot faces complexity stemming mainly from time pressure and interruptions. Consequently, the pilot needs a high skill level, even if she only occasionally participates in re-planning.

Comparing the commander and the pilot roles reveals that their sources of complexity peak in different dimensions. For the company commander, most complexity

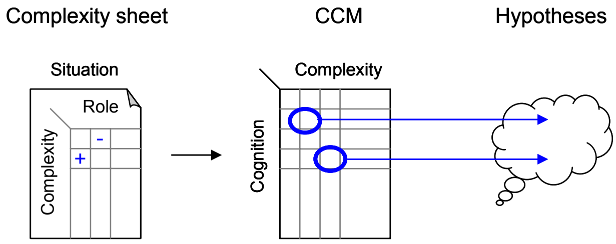

Figure 2: From complexity differences to hypotheses via the CCM model.

dimensions are rated as high or very high. This is not surprising, since re-planning is an important responsibility for her. First, dynamism is rated as very high, since many things may happen within the wide system boundaries of the commander without her intervention. In such a highly dynamic system, the nature of the problem will change over time. Therefore, context-free rules will not be sufficient for the commander to control the situation. Second, the parts dimension is also rated as very high. There are many types of cargo and personnel to account for in the re-planning situation, several helicopters to use for this task, and many routes to consider. This diversity requires that the skill level must support prioritizing and recognizing importance. Finally, the risk dimension of complexity is rated as very high. The helicopter company commander has an overarching responsibility to get the right cargo and personnel to the right places in the right time. Failure in this respect could have serious consequences. In a high-risk situation, a less skilled person would need considerable time to reflect over the circumstances and to take precautions such as consulting a more skilled person. Risk alone may in this way delay and complicate operations, which may not be admissible in a time-sensitive situation. Thus, in the re-planning situation, there are more complexity demands on the helicopter company commander than on the pilot, and the demands are of a different nature.

The cargo coordinator role has three main sources of very high complexity. First, as for the company commander, dynamism is rated as very high, since the coordinator deals with aspects pertaining both to the helicopter unit and to the airborne unit. The nature of problems can change on both sides and problems on one organization can propagate to the other. Second, uncertainty is very high for this role. This is because the coordinator receives low-level data from the two units. Particularly, data from the airborne unit are uncertain because of the unpredictable nature of that unit's ongoing mission in the area of operations. Before the coordinator has developed a sufficient model of the system, she will have difficulties judging whether the data can be trusted. Finally, dependency of others is rated as a very high source of complexity. The cargo coordinator must communicate with many other people to resolve competing goals and needs, without having formal authority to give orders to either unit.

Table 1: Complexity analysis sheet for the situation “re-planning due to difficult weather conditions and technical problems in large-scale operations”.

Complexity characteristic	*Role*			
	Pilot (A)	*Company commander (B)*	*Cargo coordinator (C)*	*Platoon leader (D)*
Dynamism	*Average*	*Very high*	*Very high*	*Average*
Parts	*Above average*	*Very high*	*High*	*Average*
Uncertainty	*Average*	*Average*	*Very high*	*High*
Risk	*Average*	*Very high*	*High*	*High*
Time pressure	*Very high*	*High*	*Above average*	*Above average*
Interruptions	*Very high*	*High*	*Average*	*High*
Feedback lag	*Average*	*Average*	*Average*	*Very high*
Dep. of others	*Average*	*High*	*Very high*	*Average*

The platoon leader scores average to high on most complexity dimensions. A distinguishing characteristic is that feedback lag is rated as very high. Since the airborne unit carry out missions in the area of operations, its elements are often out of reach of communication for various reasons. Therefore, the platoon leader must be prepared to use old data and to wait a long time before getting feedback on actions. A system with extensive feedback lag requires feedforward control and, consequently, operators with a good model of the system. A less skilled person would have great difficulties predicting future system states.

This analysis suggests that the complexity characteristics of different roles may vary significantly. Furthermore, it gives hints on where personnel with a high level of skill may be required and why.

Cognitive mode

We compare the demands on cognitive mode for the pilot and the cargo coordinator in the re-planning situation. In this analysis, we concentrate on the complexity dimensions with the largest differences between the roles.

We begin with *dynamism*, which is rated much higher for the coordinator than for the pilot. An operator in a highly dynamic system, where the nature of the problem changes over time, would require a high degree of reflective thought to grasp the problem and its ramifications. *Uncertainty* is also rated much higher for the coordinator. When the uncertainty is high, the operator can use only few stable or known “patterns” in a reactive way. The more uncertain the situation is, the more data the operator needs to reflect on. *Risk* is greater for the coordinator. If a situation comes without risk, reactive cognition would be appropriate, since failure does not lead to serious consequences. When the stakes rise, reflection becomes important to maximize the chance of success. *Time pressure* is rated much higher for the pilot. If there is minimal time available for a task, reflection will be limited, since analytical reasoning takes more time then subconscious pattern recognition. The *interruptions* dimension is also rated much higher for the pilot. As discussed earlier, an operator may have difficulties recovering from an interruption when she operates mainly in a reflective mode.

All these examples of complexity dimensions suggest that support for the pilot role should be designed to engage a reactive mode of cognition for the re-planning situation. The dimensions rated high demand it, and the dimensions rated low allow it. Conversely, the examples indicate that support for the cargo coordinator role should facilitate reflection in this situation. When developing support for re-planning, such knowledge can direct design decisions, most notably for how to represent the underlying data for different roles.

Cognitive style

We discuss how the complexity characteristics for the roles may indicate varying fit to the different cognitive styles.

We begin with the company commander role and its three peak characteristics for complexity: *dynamism*, *parts*, and *risk*. When dynamism is very high and the nature of the problem changes with time, operators have problems keeping track of details. Therefore, an operator of *global* style would probably do better than would an operator of *local* style. The situation the commander faces involves many interconnected parts, and multiple competing goals of varying importance. A person of *hierarchic* style would probably be best suited to handle these circumstances. The risk involved in this role is very high, and therefore a person of *judicial* style would seem appropriate. However, it is important to bear in mind that since time pressure is rated as high the time for analysis is limited.

When we compare the pilot and the airborne platoon leader roles, we find the greatest differences in the complexity dimensions *uncertainty*, *time pressure*, and *feedback delays*. The pilot works with data that are typically refined in several steps and the nature of her tasks are not prone to dramatic changes. The platoon leader, on the other hand, executes actions and experiences the situation directly on the site. The platoon leader must deal with data acquired in this environment to judge whether they influence re-planning. As discussed previously, the time pressure is rated high for the pilot in a re-planning situation. A platoon leader in the airborne unit is not directly involved in the re-planning situation. She may suggest changes in tasks to the commanding officer of the airborne unit, but the normal procedure is to carry out given orders and to provide situation reports. The feedback lag experienced by the platoon leader is different from that encountered by the pilot. The pilot typically maintains radio contact with many other key actors. A platoon leader would probably benefit from a *liberal* style, as a high degree of uncertainty and significant feedback lag make it difficult to establish the current state of the system as a basis to following rules and regulations. For the pilot, on the other hand, a *conservative* style may be efficient and safe, especially in the light of very high time pressure. To summarize, the analysis suggests that the pilot role might be suited for a person of a *conservative* style, whereas the airborne platoon leader role might benefit from a style closer to the *liberal*.

DISCUSSION

In this paper, we have outlined a framework for coupling characteristics of complexity and certain characteristics of cognition to aid design work for large socio-technical systems. We applied the framework to an example from the domain of military command and control. The first challenge was to identify different characteristics of complexity in the system or work domain. We showed an example that used *roles* and *situations* for analysing the complexity issues. Next, we entered the results of this analysis into the CCM and used it to formulate hypotheses about how complexity imposes constraints on skill level, cognitive mode, and cognitive style.

The cognition dimension of the CCM is subject to considerable refinement to capture the most important aspects. One question in particular is to investigate how fundamental impact cognitive styles have on the handling of complexity from various sources. All the cells in the CCM have to be investigated to provide valid guidance. Several other aspects of cognition are potentially interesting. Learning (Norman, 1993; Riding & Rayner, 1998) is one aspect that would be valuable to relate to complexity. When a crucial task or situation has been identified, how can we use its complexity characteristics as guidance in the design of a training approach? Furthermore, we can decompose the complexity dimension further to be able to map system characteristics at a greater level of detail. The representation dimension from Woods' triadic complexity model (Woods, 1988) is not considered in the current framework, but could be added to provide additional guideline attributes to each cell in the matrix, based on the principles of representation design (Woods, draft; 1995).

Finally, the *process* of working with the proposed framework to reach hypotheses is as important—if not more important—than the hypotheses themselves. It helps us gain a deeper insight into the problem domain, and makes us think about possible solutions. From this point of view, the framework outlined in this paper can be seen a tool for aiding communication between problem and solution in a design process.

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