Modelling & Simulation for Requirements Engineering and Options Analysis

Final Report

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Abstract

This report presents the results of a scoping study that was conducted to develop a Research & Development roadmap for Project 14dj, *Modelling and Simulation for Requirements Engineering and Options Analysis.* The purpose of Project 14dj is to develop a Modelling & Simulation capability, comprised of analytical techniques and software tools, for addressing human factors issues commonly encountered by Canadian Forces acquisition projects. This scoping study developed a roadmap for this research by developing insights and research questions from the current Canadian Forces procurement process, the academic and applied literature on requirements engineering and options analysis, and through expert advice on how Cognitive Work Analysis could be applied to CF procurement. 24 research questions are developed, which are structured into five specific research proposals for Defence R&D Canada to consider for inclusion in Project 14dj.

Résumé

Ce rapport présente les résultats d'une étude de délimitation de projet visant à élaborer un guide de Recherche et Développement pour le Projet 14dj, *Modélisation et simulation pour l'ingénierie des besoins et l'analyse des options.* Ce projet a pour but de développer une capacité de Modélisation et simulation composée de techniques d'analyse et d'outils logiciels, pour résoudre des questions liées aux facteurs humains qui se posent souvent dans les processus d'acquisition des Forces canadiennes. La présente étude de délimitation de projet a permis d'élaborer un guide pour cette recherche en développant des perspectives et des questions de recherche à partir du processus d'acquisition actuel des Forces canadiennes, de la littérature didactique et des études appliquées à l'ingénierie des besoins et l'analyse des options, et par des conseils éclairés sur la manière dont l'Analyse du travail cognitif peut être appliquée aux acquisitions des FC. Vingt-quatre questions de recherche sont développées et reparties en cinq projets de recherche que R&D pour la défense Canada pourra examiner et inclure dans le Projet 14dj.

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Executive summary

Modelling & Simulation for Requirements Engineering and Options Analysis: Final Report

Gerard Torenvliet; Antony Hilliard; Catherine M. Burns; Gavan Lintern; Jean-Yves Lamarre; DRDC Toronto CR 2010-049; Defence R&D Canada – Toronto; May 2010.

Introduction or background: Defence R&D Canada – Toronto has recently launched Project 14dj, titled "Modelling and Simulation for Requirements Engineering and Options Analysis". This project is an Applied Research Project to develop a Modelling & Simulation framework and associated software tools for supporting requirements engineering and options analysis. A scoping study was conducted to ensure that the research of Project 14dj is properly situated within the context of Canadian Forces procurement, current trends in requirements engineering and options analysis, and the area of practice of Cognitive Work Analysis.

Results: The scoping study developed 24 research questions that have been structured into five research proposals for inclusion in Project 14dj: (1) research to apply Cognitive Work Analysis and Modelling & Simulation to the development of operational requirements; (2) research to conduct a cognitive task analysis of requirements engineering and options analysis in Canadian Forces procurement; (3) research to develop a tool to support the application of Cognitive Work Analysis to Canadian Forces procurement; (4) research to extend and apply Social Organization and Cooperation Analysis (a lesser-developed area of Cognitive Work Analysis) to Canadian Forces procurement; and, (5) research to extend Defence R&D Canada – Toronto's crewing effectiveness task network model.

Significance: The research program presented in this report should provide Defence R&D Canada with a stronger ability to have a positive impact on Canadian Forces procurement projects. If successful, this research could provide the CF with an overall reduction of risk in the procurement cycle. This should lead to more predictable procurement projects that are better able to provide the CF with the capabilities required to meet their strategic objectives.

Future plans: The research proposals contained in this report should be structured into an overall research plan for Project 14dj.

Sommaire

Modelling & Simulation for Requirements Engineering and Options Analysis: Final Report

Gerard Torenvliet; Antony Hilliard; Catherine M. Burns; Gavan Lintern; Jean-Yves Lamarre; DRDC Toronto CR 2010-049; R & D pour la défense Canada – Toronto; Mai 2010.

Introduction ou contexte: Recherche et développement pour la défense Canada – Toronto a récemment lancé le Projet 14dj, intitulé «Modélisation et simulation pour l'ingénierie des besoins et l'analyse des options». Il s'agit d'un projet de recherches appliquées visant à développer un cadre de modélisation et simulation et des outils logiciels associés en vue d'appuyer l'ingénierie des besoins et l'analyse des options. On a mené une étude de délimitation de projet afin de vérifier que la recherche du Projet 14dj s'inscrit bien dans le contexte des acquisitions des Forces canadiennes, des tendances actuelles en matière d'ingénierie des besoins et d'analyse des options, et du domaine d'exercice de l'Analyse du travail cognitif.

Résultats: L'étude de délimitation de projet a développé 24 questions qui ont été réparties en cinq projets de recherche à inclure dans le Projet 14dj: (1) des recherches pour développer les besoins opérationnels à l'aide de l'Analyse du travail cognitif et de la modélisation et simulation; (2) des recherches pour mener une analyse du travail cognitif lié à l'ingénierie des besoins et l'analyse des options dans les acquisitions des Forces canadiennes; (3) des recherches pour élaborer un outil en vue d'appuyer l'application de l'Analyse du travail cognitif aux acquisitions des FC; (4) des recherches permettant d'étendre et d'appliquer l'Organisation sociale et l'Analyse de la coopération (un domaine moins développé de l'Analyse du travail cognitif) aux acquisitions des FC, et (5) des recherches pour étendre le modèle de réseau de tâches de R&D pour la défense Canada – Toronto de façon à améliorer l'efficacité du personnel.

Portée: Le programme de recherche présenté dans ce rapport fournira à Recherche et développement pour la Défense Canada une plus grande capacité d'exercer une influence positive sur les processus d'acquisition des FC. Si cette recherche est fructueuse, elle pourrait permettre aux FC de réduire les risques dans l'ensemble du cycle d'acquisition. Cela devrait mener à des projets d'acquisition plus prévisibles qui sont plus en mesure de fournir aux FC les capacités dont elles ont besoin pour atteindre leurs objectifs stratégiques.

Recherches futures: Les projets de recherche contenus dans le présent rapport devraient être répartis dans un plan de recherche global pour le Projet 14dj.

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1   Introduction

1.1   Background

To meet its strategic objectives, the Canadian Forces (CF) must have access to equipment appropriate to its current and future missions. To support this, the Chief of Force Development (CFD) has enacted a strategic planning process called Capability Based Planning (CBP). CBP is "an integrated process that is coherent and logical to determine the kinds of capabilities [the CF] will field in the years to come" (Chief of Force Development, 2008a, p. 1). The process develops a prioritized list of procurement projects which is updated regularly based on changes in the strategic environment. If a project is selected for procurement, the High-Level Mandatory Capabilities (HLMCs) identified in the CBP process are passed through successive operational and technical phases of analysis to capture the requirements to be fulfilled by new or modernized equipment. This is a complex process of translation (from strategic to operational to technical requirements) and trade-off (between operational needs and what is available in the marketplace).

In the majority of cases, there is a mismatch between the CF's operational needs and the equipment available in the marketplace. Instead of being able to procure Commercial-Off-The-Shelf (COTS) equipment, the Crown frequently needs to work with industry to develop a bespoke solution. For example, the in-development Maritime Helicopter Project is nominally based on the Sikorsky S-92, but comes with airframe enhancements, cockpit instrumentation, and mission systems highly customized for the program's specific requirements.

In these cases, the Crown is faced with the difficult and complex job of defining operational and technical requirements for a system that does not yet exist. These requirements need to be developed through an understanding of the ways in which operators will use the new equipment, but at a point when the complexities of the system and its operational employment are not fully understood. What is more, new systems introduce new possibilities for human work and so change how people work, usually in ways that cannot be predicted *a priori*. As a result, systems designers get caught in what has been called the task-artefact cycle (Carroll, Kellogg, & Rosson, 1991): current tasks are the basis for requirements; requirements drive the design of new artefacts; the new designs open up new possibilities for work; and the original requirements end up missing their target.
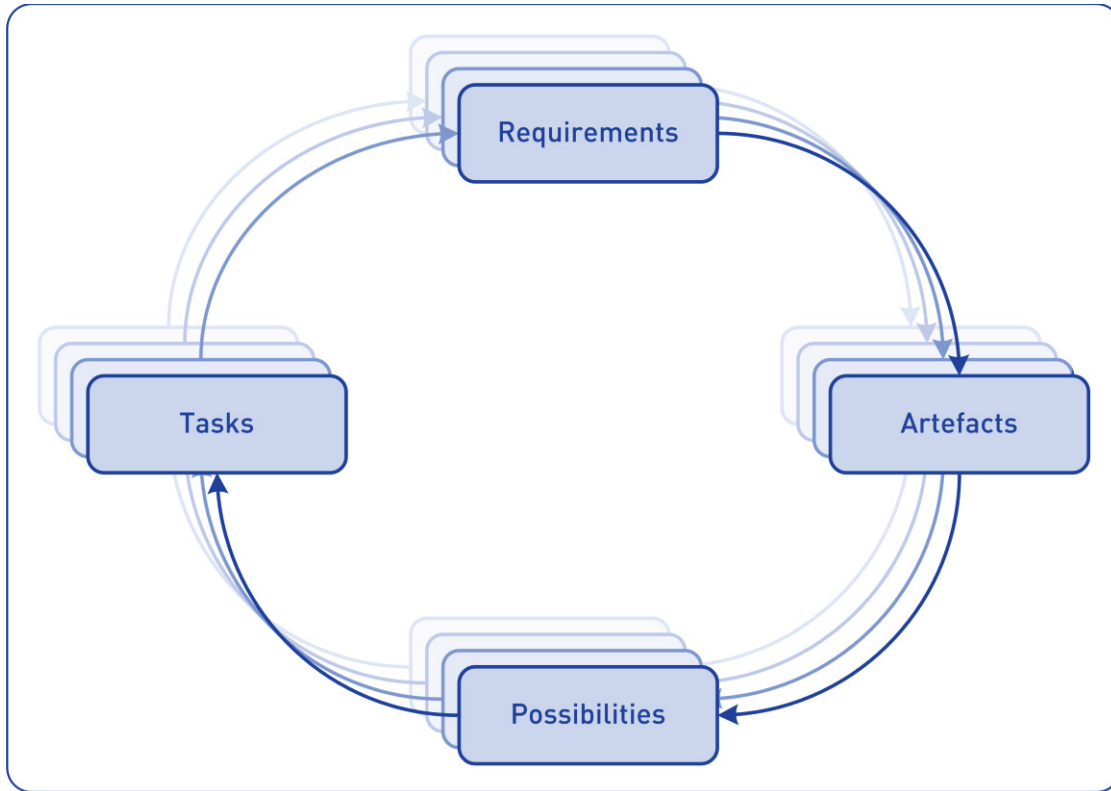
Figure 1: The task-artefact cycle (adapted from Carroll, et al., 1991).

1.2   New directions

Work to improve the development of operational and technical requirements is progressing on two fronts. First, the systems engineering community is developing techniques to improve the quality of requirements. Many different techniques have been proposed (a sampling of which is reviewed in Section 2.3), toward the overarching aim of producing individual requirements that are not prone to misinterpretation and sets of requirements that are comprehensive (Halligan, undated). This work, if successful, should improve the translation of requirements from the Crown to vendors.

Second, the cognitive engineering community is developing methods and frameworks to resolve the task-artefact cycle. One such framework is Cognitive Work Analysis (CWA; Rasmussen, Pejtersen, & Goodstein, 1994; Vicente, 1999; Vicente & Rasmussen, 1992), a type of analysis that, instead of describing current operator tasks, seeks to identify technological and organizational constraints that need to be satisfied for a system to be effective. The requirements derived from CWA are more fundamental than those developed from task-based approaches, and so systems derived from these requirements should have fewer elements that get caught in the task-artefact cycle.

1.3 Project 14dj – Modelling and simulation for requirements engineering and options analysis

Defence Research & Development Canada (DRDC) Toronto has recently launched Project 14dj, titled "Modelling and Simulation for Requirements Engineering and Options Analysis". This project is an Applied Research Project (ARP) to develop a Modelling & Simulation (M&S) framework and associated software tools for supporting requirements engineering and options analysis. While DRDC has done significant work in this area in the past, they are now interested in supplementing their current toolset with the constraint-based perspective provided by CWA. The goal of the ARP is to provide the CF with a comprehensive and hybrid M&S approach that includes constraint-based, task-based, and process-based techniques.[1]

1.4 Current work – Development of an R&D roadmap

The purpose of the work described in this report is to develop a scope for the ARP, and to formulate this scope as a Research & Development (R&D) roadmap. The R&D roadmap is intended to define the research questions that need to be answered by the ARP, and the research methods to address those questions appropriately within the ARP's three-year time horizon. The research to develop this roadmap is documented in this report, and focused on two issues:

- **The feasibility of applying CWA to requirements engineering in the CF procurement context.** To develop a roadmap for the ARP, it was important first to understand if and how CWA can be applied to requirements engineering in a military procurement context. This involved gaining an understanding of the type of constraints that can be captured by CWA that are meaningful for CF acquisitions, the types of performance metrics that can be developed for those constraints, and the prioritization among those constraints. Further, if this research is also to assist the CF in options analysis, an understanding is needed of the methods that can be used to measure the ways in which different design alternatives manage the constraint-space of a work domain, and the advantages or disadvantages of them as compared to existing task- or process-based methods. Finally, since CWA is widely considered to be a challenging analytical framework, it is important to understand if it is possible to generalize and standardize its modelling techniques and to package them into software tools.

- **The feasibility of developing an integrated modelling platform.** Since the objective of this research is to investigate the integration of CWA with existing approaches, this scoping study also investigated if it would be necessary, desirable, and feasible to integrate these techniques into a common platform, and further to investigate if that could be done while ensuring the traceability of requirements back to their source in analysis results.

The objective, context, and expected benefits of this project and of Project 14dj are summarized in Figure 2, below.

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[1] Constraint-based work analysis techniques model the constraints of a work domain that must be respected for the system to operate without faults; task-based techniques model the normative tasks that should be performed to work successfully in the domain; and process-based techniques model the processes that occur in the work domain. There is a crisp distinction between constraint-based techniques and task- and process-based modeling, but there is only a fuzzy distinction between task- and process-based modeling.

> **Project objective.** To assist DRDC in developing a Research & Development roadmap for the three-year Applied Research Project, *Modelling and Simulation for Requirements Engineering and Options Analysis*.
>
> **Applied Research Project objective.** To develop a Modelling & Simulation capability, comprised of analytical techniques and software tools, for addressing human factors issues commonly encountered in Canadian Forces acquisition projects.
>
> **Applied context.** Canadian Forces procurement; specifically, the challenges involved in developing comprehensive, meaningful, understandable, and traceable operational requirements in the early stages of procurement; in translating operational requirements into technical requirements; and in developing measurable specifications.
>
> **Benefits.** Successfully meeting the Applied Research Project's objective within the context of Canadian Forces procurement is expected to lead to a reduction of risk in the procurement cycle. This will, in turn, lead to more predictable procurement projects that are better able to provide the CF with the capabilities required to meet their strategic objectives.

Figure 2: The objective, context, and expected benefits of this project and of Project 14dj.

1.5 Approach

The project Statement of Work (SOW) structured the work to produce an R&D roadmap around a series of reviews – of the CF procurement process, of requirements engineering and options analysis practice, and of CWA. We assigned these reviews to team members with relevant expertise, and then conducted a two-day workshop to discuss and consolidate the results of these reviews into an outline for the R&D roadmap. All team members participated in the workshop, along with the DRDC scientists responsible for Project 14dj. After this workshop, the team's project engineer worked from the guidance developed at the workshop to prepare a draft R&D roadmap. The draft roadmap was revised through reviews by the team's various experts to produce the finalized R&D roadmap presented in this document.

The level of expertise brought to bear on the development of this R&D roadmap should be emphasized; while the resources allocated to this project allowed only for high-level reviews in each area, the experts consulted had a strong grasp of each of the review areas involved in this project. Our team included:

- an ex-Air Force Lieutenant Colonel with a long career of experience in CF procurement, both as an aerospace engineer in the CF and as a military program manager at a major Canadian defence contractor;

- a professor in Systems Design engineering who is a global expert in human factors and CWA; and,

- an expert in CWA who has held the post of Chief Scientist at a major US defence contractor, and who has a long career of experience in human factors engineering and design and systems engineering, both from academic and industry perspectives.

In addition to this, the team's project engineer has collaborated with DRDC on numerous research contracts, has a strong knowledge of CWA, and has led the human factors effort for an element of a major CF procurement project on behalf of a major Canadian defence contractor. The team's research assistant, a doctoral candidate in Mechanical & Industrial Engineering, also has a strong knowledge of CWA.

To ensure that this scoping study was properly informed by the DRDC context, this project has also been conducted as a strong collaboration between the project team and the scientists at DRDC Toronto involved with Project 14dj.

1.6   Document organization

This document is organized as follows:

- **Section 1 – Introduction** (this section) provides the project background, purpose, and the approach taken;

- **Section 2 – Project context** provides the results of the literature reviews conducted to develop the context for the R&D roadmap;

- **Section 3 – Research opportunities** present the research opportunities for DRDC that follow from the literature reviews and DRDC's research context; and

- **Section 4 – Conclusions** provides concluding material.

This report also includes the following annexes:

- **Annex A - Literature review of current requirements engineering practice** contains the slides prepared to summarize the results of the literature review of requirements engineering and options analysis; and,

- **Annex B – An overview of the CF procurement process** contains the slides prepared to summarize the results of the review of the CF procurement process.

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2   Project context

2.1   Introduction

As discussed in the introduction, our work to develop an R&D roadmap for Project 14dj, "Modelling and Simulation for Requirements Engineering and Options Analysis" began by conducting a series of reviews to develop the information necessary to properly situate the R&D roadmap. We conducted:

- a review of the CF procurement process, to provide information to help ensure that the R&D roadmap is targeted at relevant opportunities in the procurement process that will deliver benefits to the CF; and,

- a review of research and practice in requirements engineering and options analysis, to provide information to ensure that the R&D roadmap addresses important questions in the Requirements Engineering community and does not duplicate prior research.

In addition to this, we also combined the team's expertise in CWA to develop a series of thoughts about how the analysis structure and models from each of the five phases of CWA can be integrated into requirements engineering in general, and specifically into the CF acquisition process.

The results of the reviews are documented in Annex A (Literature review of current requirements engineering practice) and Annex B (An overview of the CF procurement process); the purpose of this section is to present some of the most relevant findings from these reviews and our team's discussions about CWA and to discuss their implications for the development of an R&D roadmap.

2.2   Canadian Forces procurement

2.2.1   General

The section provides an overview of the CF procurement process, for the purpose of identifying challenges and opportunities within that process that could be addressed by Human M&S techniques, especially as applied to questions relevant to Human Factors (HF) and Human Systems Integration (HSI). This overview is intended only to provide adequate context to the challenges and opportunities identified that motivate specific items in the proposed R&D roadmap (contained in Section 3). The references cited provide more detailed context and should be referred to as appropriate when specific research directions are engaged.

2.2.2   High-level overview of the CF procurement process

A high-level overview of the CF procurement process from the perspective of operational and technical requirements generation is shown in Figure 3, below. This figure shows the major phases in the procurement process and the typical documentation resulting from each phase.
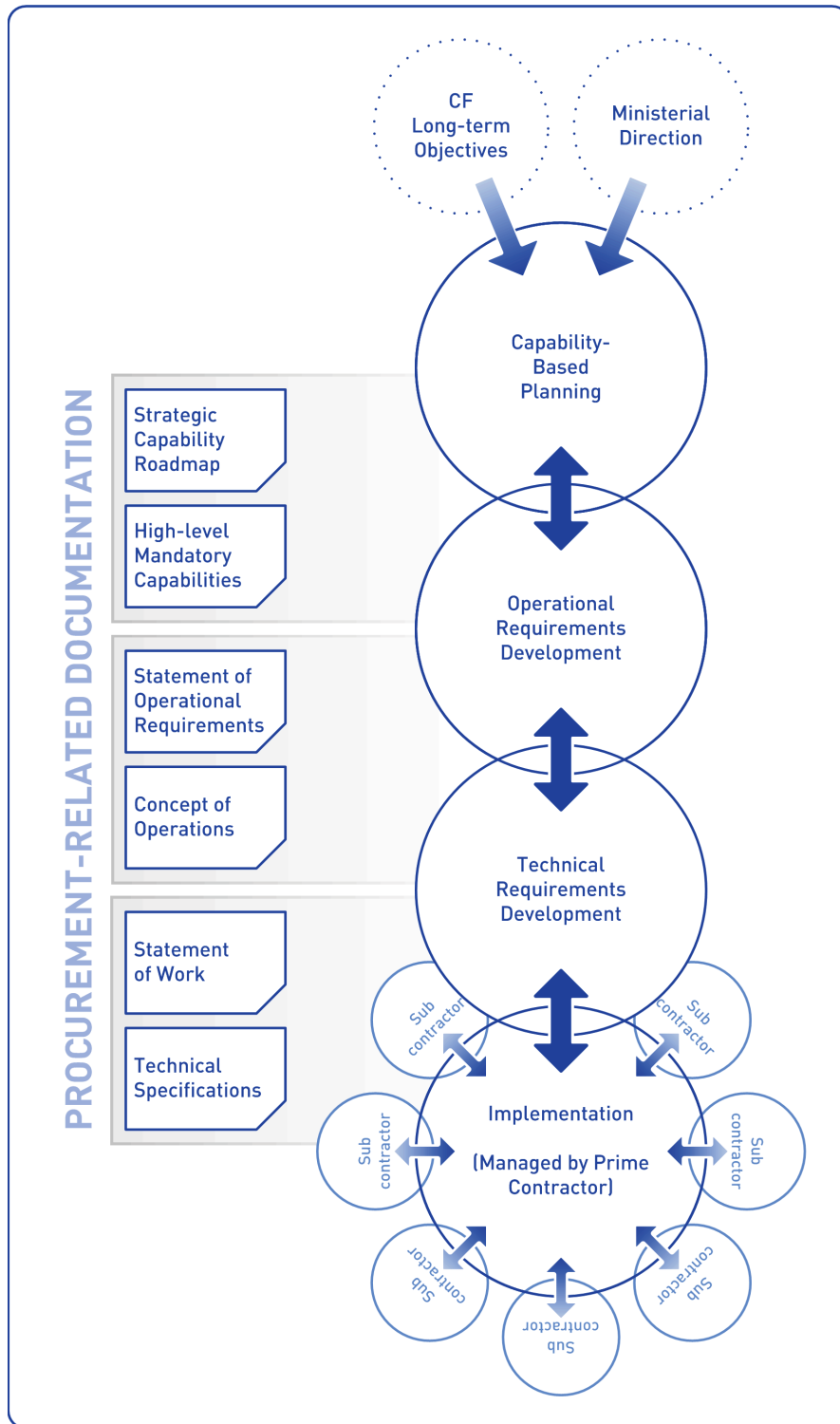
Figure 3: An overview of the CF procurement process.

Before describing each phase of this process, a number of things about the process in general should be noted:

- **The process is idealized.** As with all processes, the documented version of the CF procurement process is somewhat idealized, and every procurement project does not follow it in the same way. Some projects may follow each step in the process with substantial rigour and analysis (for example, the current Joint Unmanned Surveillance Target Acquisition System (JUSTAS) Medium Altitude Long Endurance (MALE) Unmanned Aerial Vehicle (UAV) procurement project), while other projects move from an identified capability deficiency to fielded equipment very quickly (for example, the CC-177 Globemaster procurement project). Nonetheless, the process illustrated in Figure 3 represents how the CF aims to run procurement projects, and so is a useful point-of-departure for the current work.

- **Investment and funding considerations are not depicted.** The process as depicted only shows the flow of requirements, from the identification of capability deficiencies at the strategic level through to the implementation of technical requirements and specifications at the implementation level. Parallel with this is the equally important process of developing an investment plan and finding funding for procurement projects. It is our understanding, however, that the issues related to investment fall outside of the scope of Project 14dj.

- **There are formal interfaces between each phase.** As shown by the list of procurement documents listed at the left side of Figure 3, the formal interface between each phase of the process consists of written documents. Increasingly, this documentation also includes models developed within the Department of National Defence (DND)/CF Architectural Framework (DNDAF; see Director Enterprise Architecture, 2009, for more details).

- **There are soft interfaces between each phase.** As signified by the overlap between the three core phases (capability-based planning, operational requirements development, and technical requirements development), there are interfaces between these phases that assist in the hand-over of information. This overlap can help to clarify any ambiguities in the procurement documents that form the formal interface between the phases.

- **There should ideally be feedback and recalibration between phases, both up and down the chain.** Decisions made at lower levels of the procurement process (for example, a decision made in the technical requirements development phase to, for funding reasons, relax a specific technical requirement) should ideally be linked to their impact on higher levels of the process (the impact of relaxing a technical requirement on the project's ability to satisfy the capability deficiencies it is intended to resolve).

- **Procurement projects are under-staffed and under-resourced.** Procurement projects within the CF are perceived to be chronically under-staffed and under-resourced. For this reason, the current focus in CF procurement does not seem to be on performing extensive analysis (as this could lead to so-called 'analysis paralysis'), but is rather on reducing program risk.

   Decision making relies heavily on military judgment. Many decisions need to be made over the course of the procurement process. While the procurement process makes allowance for the use of structured analysis tools and methods, there seems to be a strong default reliance on using what is termed *the best military judgment* to make decisions. The following statement in the Strategic Capability Roadmap (Chief of Force Development,

2008b) is typical: "The last step . . . was to apply *best military judgment* to refine the set of selected alternatives. Every mathematical model is limited by the factors it can take into account to produce the best objective solution. (p. 52, emphasis ours)."

- **Schedules are difficult to predict.** Subject matter experts' experience with the procurement process is that the schedule for each phase can be difficult to predict, and is rarely set in stone. Each phase may progress for long periods of time with little perceived scheduling pressure, but this situation can change rapidly if the priority of a program changes. For this reason, CF personnel are loath to involve any outside organization in the requirements development process, especially if that outside organization's efforts will be on the critical path.

Each of these phases is described in more detail in the sections that follow.

2.2.3   Policy context: Ministerial direction and CF long-term objectives

The CF reports to the Government of Canada and all activities of the CF must be made in response to government policy. Under most circumstances, government direction is expressed as a set of long-term objectives for the CF, for example, the *Canada First Defence Strategy* (Chief of Defence Staff, 2008). Government direction may also come more directly as input from the Minister of National Defence. These various forms of direction form the policy context for procurement.

CF staff developing operational or technical requirements during later stages of procurement may feel removed from this high-level policy context, but it is nonetheless important in terms of developing priorities and ensuring adequate funding for procurement. For example, the *Canada First Defence Strategy* sets a policy direction for the CF to be modernized through the procurement of at least five new types of equipment: destroyers and frigates, fixed wing search and rescue aircraft, next-generation fighter aircraft, maritime patrol aircraft, and land combat vehicles and systems. Should the policy direction from the government change, procurement projects that have progressed even to late stages may be reworked or even cancelled (for example, the Sea King replacement project, started in 1986, was cancelled in 1993 after progressing to the implementation phase). So, while the policy context may not affect the day-to-day work of developing operational and technical requirements, it is the trump card that determines whether or not the subsequent phases progress at all.

2.2.4   Capability-based planning

CBP is a high-level planning activity that is performed in response to the current policy context, with the aim of developing a prioritized list of capabilities[2] for procurement over the current planning horizon (which is typically on the order of 20 years). The long planning horizon

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[2] A capability is defined as, "A particular ability that contributes to the production of a desired effect in a given environment within a specified time and the sustainment of that effect for a specified period. Capability is delivered by an appropriate combination of PRICIE (Personnel/Leadership/Individual Training, Research and Development/Operational Research, Infrastructure, Environment and Organization, Concepts, Doctrine, Collective Training, Information Management & Technology & Equipment Support) components (Chief of Force Development, 2008a, p. 3)."

involved in CBP means that the process involves developing an understanding of the implications of current government policy on the future security context. CBP builds this understanding by developing scenarios to capture assumptions about the future security context, understanding what the response of the CF to those scenarios should be, and abstracting what the CF's current capability deficiencies are with respect to those scenarios. These deficiencies point to capabilities that should be procured. Since there is never enough money, people, or time for the CF to address every capability deficiency, CBP also includes processes for prioritizing the capabilities that the CF needs to acquire.

The most important output of the CBP process is the *Strategic Capability Roadmap* (SCR) (Chief of Force Development, 2008b). The SCR is a comprehensive document that captures all of the results of the CBP process to "provide rigour and logic to planning for future CF capabilities" (Chief of Force Development, 2008b, p. iii). It includes documentation of: the future security context and the way the CF is envisioned to respond to that environment; the problem space of capability deficiencies; the solution space of capability alternatives; the integration space of prioritized capabilities for future development; important development risks that could delay the closure of deficiencies, and recommendations for developing an investment plan to provide the capabilities required. In terms of providing a robust and well-considered direction for future procurement projects, the SCR is impressive in scope and detail. The most recent version of the SCR at the time of writing includes a prioritized list of 319 capabilities, ranging from the Canadian Surface Combatant (priorities one and two) to a personal anti-armour weapon system (priority 319).

2.2.5   Operational requirements development

If a project identified in the CBP is given preliminary funding,[3] the project is allocated to one of the environments (Army, Navy, or Air Force) and a group of operators[4] are assigned the responsibility of using their knowledge to develop an operational vision and requirements for the capability. While we were not able to locate documentation about the work processes followed during this phase, the phase has two main outputs:

- **Concept of Operations (ConOps).** The ConOps is intended to capture a relatively detailed operational vision of how a capability will be employed, including system operation, force generation and training, maintenance, command and control, and operational structure, to a sufficient level of detail to guide further development; some sample text from the JUSTAS ConOps is shown in Figure 4, below. It is the authors' opinion that ConOps are not typically developed as requirements, but rather as a detailed account of the envisioned system sufficient to inform the development of operational requirements.

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[3] The development of an investment plan to accompany the SCR is an important activity, but details of investment are largely outside of the scope of this research. Interested readers are referred to the SCR document, especially Chapter 7, for details of how the SCR is transformed into an investment plan.

[4] In military parlance, *operators* are to be distinguished from *engineers*. Operators are the personnel who use equipment to generate effects (e.g., flying an aircraft to deliver munitions; sailing a ship to project force; using an infrared sensor to gather intelligence) and engineers are the personnel who manage that equipment so that it can be operated (e.g., engine-room artificers on a ship; aerospace engineers in a squadron).

- **Statement of Operational Requirement (SOR)**. The SOR follows from the ConOps and defines the operational requirements for a new system in sufficient detail for the project to move from the development of operational requirements to the development of technical requirements. The SOR should be clearly linked to a capability deficiency (see Figure 5, below). The SOR contains a large number of detailed operational requirements related to all aspects of system operation, maintenance, training, and force generation, separated into mandatory and rated requirements[5] (see Figure 6, below). All mandatory requirements typically trace back to a set of High-Level Mandatory Capabilities (HLMCs; see Figure 7, below).

While these documents are intended to fully capture the operators' understanding of the operational requirements for the system to be procured, there are four important considerations that make the development of complete and consistent operational requirements challenging.

- **Lack of technical context.** Operational requirements are developed by personnel who do not necessarily have a good understanding of the technical constraints on system operation (and, who cannot be expected to have that knowledge). This can lead to operational requirements that are challenging, or impossible, to implement from a technical perspective.

- **Impact of tacit knowledge.** Operational requirements are developed by personnel who have much tacit knowledge about the area for which they are developing requirements. This tacit knowledge may never be properly expressed for transfer to personnel without it.

- **Narrow inquiry.** Operational requirements are developed by personnel who may not understand the full scope of concerns to account for in requirements development. An operator with a strong interest in one area (for example, littoral operations) may not fully appreciate the concerns of other areas (for example, overland operations). As a result, some requirements categories may be over-represented while others are under-represented.

- **Task-artefact cycle effects.** The operational requirements that are developed are frequently based on operators' understanding of how to achieve missions with similar legacy equipment, and so they are especially prone to getting caught in the task-artefact cycle (see Section 1.1).

To help mitigate the effects of these challenges, the interface between the development of operational and technical requirements should be robust. Not only should the relevant documents be passed down from one phase to the next, but operational personnel familiar with the operational requirements for a new system should be employed in the Project Management Office (PMO) responsible for technical requirements development. Unfortunately, operational personnel are, in practice, rarely employed in the PMO, making this interface an important overall project risk.

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[5] Requirements that must be fulfilled for the system to address the capability deficiency are categorized as *mandatory*, whereas requirements that do not bear on whether or not a system meets the capability deficiency but rather which have the potential to improve the way in which the system provides its capability are categorized as *rated*. In later stages of procurement, mandatory requirements correspond to items that a potential vendor must deliver for their system to be considered compliant to the Crown's needs, whereas rated requirements are scored to help in identifying the system that is best from a technical perspective.

3.3 Methods of UAV Control. Both the air vehicle and the payload are remotely controlled. Control is normally exercised in one of three ways: LOS, BLOS, or autonomous.

    a. LOS – is defined as the condition where the air vehicle (AV) is controlled via a data link that has an unobstructed view from transmitter to receiver. Takeoffs and landings are performed using LOS. Mission planning for takeoffs and landings is critical as operating altitude, range between the receiver and transmitter, surrounding terrain elevation, ground based transmitter and receiver location and security will greatly affect the UAV's launch and recovery. Missions may be conducted in LOS mode.

    b. BLOS – is defined as the condition where the AV and payload are controlled via a satellite communications data link and / or other extended communication link and is the normal control mode for MALE UAV operations. The UAV mission will be conducted using BLOS communication. Two new factors need to be considered with this control method: Satellite Visual Horizon (SVH – the look angle from the UAV) and Satellite Transponder availability.

    c. Autonomous – is defined as pre-programmed flight profile used when the UAV self-manoeuvres along a flight profile. It could be employed when the command link is lost and the UAV attempts to regain the command link.

Figure 4: Some sample content from the JUSTAS ConOps.

1.5 Deficiency

1.5.1 Canadian international operations have highlighted deficiencies in the provision of accurate and timely intelligence, surveillance, reconnaissance and target acquisition information to CF commanders. In particular, there are insufficient numbers and types of sensors for both force employment and force generation. In addition to sensor deficiencies, the CF does not have an extended endurance precision strike capability that is able to respond to time-critical emerging targets. These deficiencies have the potential to lead to significant gaps in the understanding of the operational situation, thereby placing mission success and CF personnel at higher risk. The acquisition of the CU161 Sperwer tactical UAV (TUAV) in support of Operation ATHENA and Operation ARCHER provided an opportunity to assess the effectiveness of this type of UAV in addressing some of these deficiencies. Sperwer has demonstrated the effectiveness of a UAV in a hostile environment; however, it is expected to be phased out by Feb 2009 as it reaches its estimated life expectancy (ELE). Project Noctua will lease the CU170 Heron as an interim UAV system to support Canadian troops in Afghanistan. The Noctua contract will be for two years of deployed operations with options to extend for up to 12 months (Dec 2011). To ensure the CF does not experience an operational gap in UAV capability, the acquisition of a follow-on, long-term UAV capability to address deficiencies is a high priority.

Figure 5: The operational deficiency stated in the JUSTAS SOR.

5   SUB-SYSTEM EFFECTIVENESS REQUIREMENTS

5.1   Air Vehicle

5.1.1 Mandatory requirements:

a.   The air vehicle, at reconnaissance mission weight and configuration, shall be capable of conducting persistent surveillance (a minimum 12 hrs) at a minimum operating radius of 1000 km from the point of departure and return with sufficient fuel for two hours of loiter (zero wind, standard atmosphere);

b.   The air vehicle, at reconnaissance mission weight and configuration, shall be capable of transiting 1000 km within three (3) hours (zero wind, standard atmosphere);

c.   The air vehicle, at reconnaissance mission weight and configuration, shall be capable of operating at 30,000 ft MSL and below;

5.1.2 Rated requirements. The UAV system will be assessed with respect to the following air vehicle requirements:

a.   Ability of the air vehicle, at reconnaissance mission weight and configuration, to take off or land in significantly less than 8000 ft;

b.   Ability of the air vehicle, at reconnaissance mission weight and configuration, to conduct persistent surveillance in excess of 12 hours at a minimum operating radius of 1000 km from the point of departure and return with sufficient fuel for two hours of loiter;

c.   Ability of the air vehicle to operate at flight altitudes of greater than 30,000 ft (MSL) at mission weight and configuration;

d.   Ability of the air vehicle, at reconnaissance mission weight, to take-off and land with a wind at 15 knots or greater at 90 degrees to the runway (wet runway), day and night;

Figure 6: Examples of mandatory and rated requirements from the JUSTAS SOR.

High Level Mandatory Capabilities
Surveillance and Target Acquisition: A suite of sensors that enables the operator to covertly detect and identify targets and obtain targeting data, in specified adverse weather conditions, from medium altitude, day and night.
Range/Endurance: Flying endurance, at mission weight, to ensure a relevant radius of operation (a minimum of 1000 km) and allow prolonged (a minimum of 12 hours) on station surveillance.
Operations Tempo: Sufficient operational and training systems, personnel, infrastructure, and logistical support to sustain two lines of tasking at a single deployment location, as well as force generation in Canada.
Interoperability: Ability of the system to provide services and data to, and accept services and data from, Joint and Combined forces.
Operational Suitability: Ability to conduct sustained operations worldwide in appropriate classes of airspace, under specified adverse weather conditions, and in low-to-medium threat environments. Provides spectrum supportability in Canada and abroad.
Dynamic Control and Responsiveness: Ability to dynamically control the air vehicle and payload, in near-real time, under line of sight (LOS), beyond line of sight (BLOS), and remote split operations, and respond rapidly to situational changes and new taskings.
Flexibility/Growth Capacity: The air vehicle must possess the demonstrated flexibility, growth capacity, and standard interfaces required to integrate new payloads to support enhanced overland capabilities and maritime domain awareness.
Force Application: Capable of enabling Joint Fires, and carrying and employing precision-guided munitions (PGM).

Figure 7: The HLMCs from the JUSTAS SOR.

2.2.6 Technical requirements development

Once the operational requirements for a new system have been developed, the procurement effort goes through a penultimate round of funding decisions to determine if the project should proceed to the level of technical requirements development. If a project gets to this stage, it indicates a high level of commitment by the CF (and the Treasury Board) to the project, as the outputs of this phase are the technical aspects of the Request for Proposal (RFP) that will be submitted to vendors for the purpose of eliciting bids, and ultimately, selecting a contractor to provide the system.

Technical requirements development is supported by a PMO, whose responsibility is to decompose the operational requirements into technical requirements that specify the attributes of the system to a level of detail that supports procurement. This is a challenging task. Looking up the requirements chain to the operational requirements, the engineers developing technical requirements must have a strong grasp of the operational requirements. As mentioned in Section 2.2.5, this is supported by supplementing the PMO with operational personnel. However, even

with this support it can be expected that there will be challenges in bridging from operational to technical requirements because operators and engineers come at the work from different perspectives. Looking down the requirements chain to the implementation phase, it can be challenging to develop appropriately detailed, complete, and consistent technical requirements. Requirements specified at a high-level may have a higher likelihood of providing complete coverage of the problem space, but they may provide vendors with so much flexibility that the resultant system will not meet the CF's operational needs. Conversely, requirements specified at a low-level may have a higher likelihood of satisfying the CF's operational needs, but they may also constrain vendors so severely that the system may end up costing significantly more than if vendors were allowed more flexibility.

Two types of documents typically result from this phase. First is a project SOW, that defines the *how* the work to deliver the system should be undertaken by a vendor. Second are the technical specifications that define *what* system should be delivered. The package of documentation that results from this phase of work can be extensive and detailed. For example, the Maritime Helicopter (MH) RFP (released on 11 April 2003) included 13 volumes, as follows:

- Volume 1 – General instructions to bidders
- Volume 2 – Proposal requirements
- Volume 3 – Evaluation plan
- Volume 4 – MH model contract
- Volume 5 – MH SOW
- Volume 6 – MH Requirements Specification (MHRS)
- Volume 7 – MH statement of operating intent
- Volume 8 – MH Contractor Data Requirements List (CDRL) and Data Item Descriptions (DIDs)
- Volume 9 – MH in-service support model contract
- Volume 10 – MH in-service support SOW
- Volume 11 – Life-cycle support requirements specification
- Volume 12 – Statement of support intent
- Volume 13 – In-service support CDRL and DIDs

While only one of the volumes, the MHRS (Volume 6) focuses on technical requirements, this volume has 256 pages, over 113,000 words, and 14 appendices (some sample requirements from this document are provided in Figure 8, below). Within a set of technical requirements of this breadth, implementation efforts will certainly reveal problems of inconsistency and incompleteness. Even though the staff working on these requirements were likely diligent and motivated, requirements engineering is a wicked problem[6] (Bubenko, 1995; Yeh, 1984) for which even the definition of what constitutes a correct solution does not exist.

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[6] With respect to requirements engineering for software projects, Yeh (1984) characterizes a problem as wicked when it has one or more of the following five characteristics: (1) the problem formulation and its

> **3.10.3 Automatic Transition**
>
> 3.10.3.1   AFCS automatic transition to a pilot-selected ground speed, heading and either radar altitude or barometric altitude shall be provided from anywhere inside the SERVICE ENVELOPE.
>
> 3.10.3.2   The AFCS automatic transition shall generate a maximum rate of descent of 500 feet per minute during any transition phase.
>
> 3.10.3.3   The MH shall be able to perform an AFCS automatic transition to a helicopter generated "into wind" hover.
>
> 3.10.3.4   The automatic transition shall take less than 95 seconds from a gate of 150 feet AGL at 120 KIAS down to the selected and programmed hover altitude.
>
> 3.10.3.5   The automatic transition "into wind" heading shall be achieved prior to the helicopter descending below 100 feet AGL.
>
> 3.10.3.6   The MH shall be able to conduct an AFCS automatic transition within five minutes after first launch from a HFX in conditions described in Section 3.5.1 of this RS.

Figure 8: A subset of the requirements for the Automatic Flight Control System (AFCS) from the MHRS.

2.2.7   Implementation

The phases of procurement described so far can all be considered to be within the problem-space of procurement, and define, with increasing levels of specificity, the procurement problem the Crown needs to resolve. The question of interest is, "How can the Crown's needs best be described?" As soon as an RFP for a procurement project is released to the vendor community, the work of requirements engineering transitions from the problem-space to the solution-space. The important question here is, "What system can industry propose and provide that best meets the Crown's needs?"

Working specifically from the requirements perspective, the vendor ultimately selected to provide the Crown with a new system uses the Crown's requirements as a starting point to develop a design that satisfies the Crown's requirements. Assuming a project that involves hardware and software components, vendors will generate their own set of high-level requirements with an organization and terminology that conforms to their chosen system architecture and that also responds to all of the Crown's requirements. Following from this, requirements will be developed to a very low level to actually specify the design that the vendor will provide. For example, it is a best practice that one low-level software requirement be written to drive the production of every approximately 10 lines of code.

As requirements are developed to increasingly low-levels of design detail, vendors typically encounter at least the following three classes of problems in understanding and implementing the Crown's requirements:

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solution cannot be separated; (2) there are no rules to determine when a solution is complete; (3) symptoms and causes cannot be distinguished; (4) the problem is substantially unique; and, (5) exhaustive and definite problem formulation are not possible. This leads Yeh to observe, "These five characteristics lead to a set of nasty attributes which are common among large [technology] systems. Such systems are: hard to define, hard to plan, hard to manage, hard to schedule, [and] hard to test. (p. 18)."

- **Interpretation.** The Crown's requirements may have seemed clear at the time they were written. However, when those same requirements are read by the vendor, whose personnel have different backgrounds and experiences, they may be difficult to interpret.

- **Inconsistency.** The Crown's requirements may also have seemed consistent at the time they were written. However, when those same requirements are viewed through the lens of the vendor's proposed solution, some of them may seem inconsistent.

- **Incompleteness.** Finally, it is difficult to imagine that a PMO would issue a set of requirements that they felt were incomplete in any substantial way. However, as a design coalesces around a set of requirements, incomplete requirements may be exposed.

In the authors' opinion, these problems have three root causes:

- **Tacit knowledge.** CF personnel who develop requirements typically have a great deal of tacit knowledge about the problem space that may not be shared by vendor personnel. Since this knowledge is tacit, there is a low likelihood that CF personnel reviewing a requirements document will notice that it is missing.

- **Unstated assumptions.** Related to tacit knowledge, CF personnel may also have assumptions about how they would expect a requirement to be interpreted or a problem to be solved. While some of these assumptions may be shared by vendor personnel, others may not be.

- **The gulf between the problem space and the solution space.** As CF personnel develop a set of requirements, it is likely that each person involved in the process has their own mental model of what they expect the solution to be, and define their portion of the problem around that solution. In cases where these mental models do not conform with the chosen solution, there will likely be a mismatch as attempts are made apply the requirements defined around one solution to another solution.

These problems are typically solved either by the vendor imposing an interpretation and taking it on risk that the interpretation was correct (which is often a reasonable thing to do to ensure that a project meets its cost and schedule targets), or by the vendor conferring with the Crown through a memorandum or a working-group meeting. Interestingly, conferring with the Crown may not lead directly to a correct interpretation of a requirement. Due to the cycle of military postings, the personnel involved in implementation-level working-group meetings will likely not be the same personnel involved in writing the technical requirements.

As a final note, most major procurement projects do not involve just a single vendor, but rather a vendor consortium with a prime contractor and many sub-contractors. While this arrangement is typically the only way for vendors to successfully respond to a major Crown RFP, it only exacerbates the problems noted in this section.

2.3　Requirements engineering and options analysis

2.3.1　Introduction

Challenges in CF procurement may overlap with those encountered in other domains and discussed in the academic literature. To ensure that this R&D roadmap incorporates best practices from other fields, does not duplicate prior work, and addresses questions of interest to the requirements engineering community, we briefly review the requirements engineering and options analysis literature.

First, we note some differences between the domains in which requirements engineering is practiced and the CF with respect to workflow, client-vendor relations, and complexity of projects. Next, we provide a brief survey of the requirements engineering methods advocated by researchers and those used in practice. Finally, we discuss work already completed in applying CWA methods in military procurement, and opportunities to build on this progress in the R&D roadmap.

2.3.2　Domains & comparison to CF

Requirements engineering is not a stand-alone profession, and at least three main communities of practice contribute to the literature: software development, business project management, and sociotechnical systems practice. Before discussing requirements engineering and options analysis methods, it is useful to consider some of the work demands that have influenced their evolution.

Software development has a rich history of requirements engineering research field (Cheng & Atlee, 2007), in part due to the complexity of software projects, and in part because of the difficulty of efficiently and completely implementing requirements in machine code. The need for efficiency is self-reinforcing in two ways: companies using efficient requirements engineering methods may be more profitable, and widely-adopted requirements engineering methods will be more likely to attract efficiency-boosting support tools. Unlike requirements engineering methods in the CF, software methods deal primarily with low-level implementation requirements.

Business project management requirements engineering methods are discussed more by industry groups (Haskins, 2007) and management consultants (Gilb & Gilb, 2007; Halligan, undated; Philbin, 2008) than in the academic literature. Much business requirements engineering is concerned with managing clients' expectations, smoothing contractual negotiations, and supporting cost and effort estimation. Some organizations like the National Aeronautics and Space Administration (NASA) develop first-of-a-kind systems, but this is uncommon. Business practices encourage early and continuous client-vendor communication to elicit and negotiate requirements.

Finally, **socio-technical systems and cognitive engineering practice** is often discussed from a consultant's or internal champion's perspective. More has been written about how requirements should be realized (e.g., the literature on developing effective designs (Crandall, Klein, & Hoffman, 2006) and clearly communicating design specifications (Miller & Vicente, 2001)) than about developing the requirements themselves. Even though this is the case, much of this work

has been done and has been effective within military contexts (e.g., Bisantz et al., 2003; Chalmers, Easter, & Potter, 2000; Hagenaars, 2003; Miller, 2004).

2.3.3   Requirements engineering and options analysis techniques used

The fields of practice described above have cultivated different requirements engineering and options analysis methods. We considered these methods as functional, goal-oriented, expert-mediating, or work-analysis based. Each reflects the needs of a particular work practice, and suggests implications for research and development of requirements engineering and options analysis methods.

- **Functional requirements engineering.** Functional requirements engineering approaches are most often discussed in the software engineering community, and include modeling tools such as the Unified Modeling Language (UML) (van Lamsweerde, 2000) and Systems Modeling Language (SysML) (Haskins, 2007). They are typically applied by software developers through:

  - Developing use cases, each a set of goal-directed scenarios.

  - For each scenario, identifying domain concepts & relationships between concepts required to accomplish the scenario goal.

  - Translating the set of concepts and relationships into system functional requirements to be implemented with compatible methods such as object-oriented programming.

  Functional requirements engineering approaches seek to describe only what a system is required to do, using rigorous structures that can be manipulated by support tools to manage large requirement sets (INCOSE Tools Database Working Group, undated), and translated into software implementations with minimal re-work (Castro, Kolp, & Mylopoulos, 2002). However, this well-formed structure is achieved at the cost of omitting requirements that cannot be described in terms of functions, such as security, safety, or fault-tolerance. Such *non-functional requirements* are omitted from modeling (Castro, et al., 2002) and relegated to supporting documents. Also omitted are the whys underlying requirements, which may hamper third parties in charitably interpreting requirements and evaluating design options.

- **Goal-oriented requirements engineering.** Deficiencies in functional requirements engineering methods have been described at length to justify development of goal-directed software requirements engineering methods. Two examples are KAOS, a goal-augmented functional method (van Lamsweerde, 2000) and i*, a social dependency-oriented method (Yu, 1997). Both include analysis frameworks and graphical notations for describing both functional and non-functional system requirements and the goal-directed relations between them. However, neither has been adopted in practice, and we could not find application examples for high-level sociotechnical system requirements.

  The history of software requirements engineering methods suggests two implications for a requirements engineering R&D roadmap. Firstly, methods to manage high-level requirements should include a structured representation of the whys that justify functional requirements. Secondly, any requirements engineering method will be more easily adopted if its notations and intermediate products are useful to others besides requirements engineers.

- **Expert-mediating methods.** The intentions behind functional requirements can often be inferred by domain experts, and one category of requirements engineering and options analysis methods leverages this. Such expert-scorekeeping methods help mediate and organize domain experts' evaluations using simple function-priority or risk-cost taxonomies and spreadsheet-like propagation of experts' cost or probability estimates. Similar methods are used to draft early-stage requirements for first-of-a-kind NASA missions (Feather & Cornford, 2003) and to manage contract work by producers of consumer equipment (Gilb & Gilb, 2007; Philbin, 2008).

  These methods are intended to be used early in the requirements process, and can blur the distinction between options analysis and requirements engineering. As long as a comprehensive expert team can be assembled, abstract and ill-defined requirements can be reconciled without support from theory-guided analyses. If expert assessment is not effective or requirements are contractually sensitive, these methods suggest specifying requirements in terms of empirical user performance criteria (Gilb & Gilb, 2007).

Three implications from this field of practice are that:

- options analysis may occur in parallel with, and is not typically referred to as separate from, requirements engineering;

- expert judgment can incorporate intent and abstract requirements, but existing representation tools may not effectively communicate their deliberations; and,

- if human-centered requirements cannot be empirically tested, such as in early-stage CF procurement, simulation methods may hold promise.

The final field of practice that we reviewed was sociotechnical systems design and cognitive engineering. Discussion of requirements in these fields has typically been taken to mean computer interface 'information requirements' (Miller & Vicente, 2001), or has been conflated with design specifications. Methods in the sociotechnical systems design and cognitive engineering fields tend towards supporting creative designer judgment (Crandall, et al., 2006) or specifying analysis steps intended to ensure effective designs (Gualtieri, Szymczak, & Elm, 2005).

An implication from this practice has already been recognized by the software and product design practice: requirements (what) must be distinguished from design specifications (how) (Gilb & Gilb, 2007).

2.3.4   Case study of CWA for requirements engineering

In Section 2.4, below, we discuss the application of CWA, a set of analysis techniques and modelling tools for analysing complex sociotechnical systems, to requirements engineering. In our review of the requirements engineering literature we learned of a previous successful application of CWA to requirements engineering and options analysis by the Australian Defense Science and Technology Organization. Published accounts include tender evaluation (Naikar & Sanderson, 2001) and crew configuration (Naikar, Pearce, Drumm, & Sanderson, 2003), while work is ongoing on evaluating UAV staffing requirements (Elix & Naikar, 2009). Details of methods are described in Annex A, so only a brief overview is discussed here.

The first application used Work-Domain Analysis (WDA) as an options analysis support tool. Similar to expert-scorekeeping methods, technical focus groups first assessed the subsystem-level functionality of each option. The resulting evaluations were then abstracted using WDA means-ends links to help estimate the effect of each subsystem's functionality on system processes, values, and purposes. Next, WDA was used to structure a comparison between all options for evaluation by a military decision-making committee (Naikar & Sanderson, 2001). The structured translation from concrete, specialized functions to abstract, operationally relevant processes and values helped manage a project of large scope without software support tools, and also helped to coordinate small teams of specialized technical experts. While this work was successful, it has some important limitations in the context of the current work: it considered only options analysis, and not requirements generation; it required high-level commitment of a kind that may be difficult to get within the CF for this type of work; it was very time-consuming; and no follow-ups or duplications have been reported in the literature. Further, it is possible that a judicious application of M&S could have packaged the insights of experts and so increased overall efficiency by reducing the amount of time that experts were required to spend on this project.

A second application used Control Tasks Analysis (ConTA), WDA, and Social Organization and Cooperation Analysis (SOCA) to evaluate crewing requirements. First, scenarios were developed to put work situations and activities in context, similar to a functional requirements engineering approach. However, ConTA was used to systematically develop as comprehensive scenarios as possible. Experts then assessed how each crewing configuration would affect scenario response, and estimated effects on WDA-derived criteria (Naikar, et al., 2003). ConTA was then used to systematically integrate scenario-specific evaluations into more general activities and situations. By comparing crew configurations on measures such as frequency of role reallocation and quantity of overhead communication, the most promising social organization was justified to operational staff and included in the vendor's system design. Again, while this work was successful, it suffers from some limitations in the context of Project 14dj: the work was done in the implementation phase and not during requirements development, and it again required significant staff commitments to organize and participate in multiple tabletop focus group sessions.

This R&D roadmap should build on the demonstrated success of CWA in a military acquisition context. Opportunities for future work identified by software practitioners (Cheng & Atlee, 2007) and justifications given for using CWA overlap significantly, suggesting that CWA applications will address research questions of interest to many practitioners.

First, since human & technology requirements are interdependent and interacting, requirements engineering frameworks must be developed to capture both intentions and technology (Cheng & Atlee, 2007; Naikar & Sanderson, 2001). However, Naikar's work was completely independent from any simulation evaluations of technological requirements, and only the final evaluation committee integrated the findings (Naikar & Sanderson, 2001). Extending CWA to better integrate M&S capabilities might improve the usefulness of M&S results and reduce the time required for their application.

A second justification for CWA in requirements engineering is that military systems require flexible, innovative problem solving and are more likely to be first-of-a-kind systems. Thus requirements engineering methods that are scenario or task-dependent may not capture functionality needed for flexibility (Naikar & Sanderson, 2001), and expertise that might

anticipate such deficiencies may not yet exist (Naikar, et al., 2003). Software requirements engineering practitioners (Cheng & Atlee, 2007) also recognize the need to specify requirements for adaptability and fault-tolerance. However, CWA methods to date still rely heavily on priming experts with scenarios, and comprehensive scenario development may not be possible for larger scope projects. Methods for narrowing the scope of scenario-primed expert judgment may help in making more effective use of scare domain expert resources and improve requirements engineering effectiveness. This could be accomplished through more effective interview notations (Elix & Naikar, 2009; Naikar, Moylan, & Pearce, 2006), by using modeling capabilities to construct a minimal set of critical scenarios, or by using simulation capabilities to animate scenario operations, workload, and crewing allocations to prime expert evaluations.

2.3.5   Insights from the literature

The following is a list of some of the insights from the requirements engineering and options analysis literature that could be relevant in the context of Project 14dj:

- **Options analysis is best considered as another type of requirements engineering.** While there may be times when the requirements engineering process is more or less in the mode of trading off options against one another, the fact that a requirement is needed implies that there are some other options that are being rejected. This implies that any techniques that assist in requirements engineering have promise to assist options analysis, and vice-versa.

- **Requirements need context.** Current requirements engineering practice seems to be to ensure that requirements are measurable statements of *what* should be, while omitting *why* the what should be and *how* the what should happen. While this supports the development of testable requirements, it also increases the potential that requirements will be misunderstood.

- **Requirements do not always benefit from context.** While requirements should be presented along with their context, requirements notation should separate intent (why) and specifications (how) from requirements (what). This will ensure that aspects of the requirements that need to be testable and measurable stay that way.

- **Requirements have a larger audience than just HF practitioners.** For a requirements engineering method to be adopted, relevance to product development workflow, minimization of contractual risks, and efficiency of use are important criteria.

- **M&S can assist in the development of measurable and testable human-related requirements.** Since M&S techniques are inherently focused on the use of metrics to evaluate performance, M&S efforts can assist in developing measurable and testable requirements by contributing and providing rationale for performance measures.

2.4   Cognitive Work Analysis

2.4.1   Introduction

CWA is a set of analysis techniques and modelling tools for analysing complex sociotechnical systems. CWA is a *formative* framework, which means that it is especially useful for helping to form an understanding of a how an envisioned system could work. While it is typically positioned

in opposition to other forms of HF analysis (such as MIL-HDBK-46855 Mission, Function, and Task analysis), CWA is best thought of as complementary to these techniques. CWA's unique contribution to the HF toolset is a focus on the essential constraints of the workspace: it describes not what people should do, or what they actually do, but rather tries to capture the constraint space that describes all that people could do.

The purpose of this section is not to present a detailed account of CWA (this has already been done elsewhere in the literature; see Burns & Hajdukiewicz, 2004; Lintern, 2009; Naikar, Hopcroft, & Moylan, 2005; Rasmussen, et al., 1994; Vicente, 1999), but rather to pose some questions on the way in which CWA could be applied to requirements engineering and options analysis for CF procurement. We generated the questions listed below in a group discussion in which we worked through the five phases of CWA to develop thoughts on how each phase could potentially be applied to and benefit requirements engineering and options analysis for CF procurement. The following two sections present a number of insights about CWA that could be relevant to Project 14dj.

2.4.2   Insights about CWA in the context of CF procurement

The following is a list of some of the insights about CWA that could be relevant in the context of Project 14dj:

- **Importance of and potential for functional analysis.** Whether it is implicit or explicit, all requirements development must be based on a functional model of the system under analysis. In our review of CF procurement, we noted that requirements development may frequently be based on an assumed (implicit) implementation model, but we did not find any evidence of any explicit functional modelling[7] outside of the current proposal to use the DNDAF. We also noted the challenges that are caused by the tacit knowledge and unstated assumptions that are involved in each phase of requirements development. In this context, it is possible that the first phase of CWA, WDA, could be used to develop an explicit functional model of the system under analysis. Not only will this make explicit a model that must already be developed implicitly, it could also point to and clarify the presence of tacit knowledge or assumptions in the requirements development process. Further, because WDA produces models that are relevant to understanding human decision-making, this effort would help to insert an early emphasis on human performance and decision-making into the requirements engineering process. Finally, if the analysis were explicit, there is a greater likelihood that it would be more comprehensive and would include consideration of all relevant factors.

- **Relevance of *why* and *how* to understanding *what* a requirement is about.** As discussed in the review of requirements engineering and options analysis (Section 2.3), requirements engineering practice prefers to develop requirements that capture only *what* is required, stripping out *why* that is required and *how* it will be provided. However, it is likely that stripping this context from requirements may make it more difficult for participants in the process to know where the requirements were affected by tacit knowledge and unstated assumptions. It is possible that structuring requirements around the Abstraction-Decomposition Space (ADS), and especially by focusing on the means-ends links (that

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[7] We suspect that our finding is more indicative of the fact that our research was limited than that no functional modeling is a part of the CF procurement process. More research is needed here.

provide the *why* and *how* context for the *what* of each node in the model) may help to provide this important context.

- **Challenges in the application of CWA.** Applying CWA is challenging, both because the modelling representations (e.g., the ADS and the Decision Ladder) have important subtleties, and because it is based on a challenging theoretical framework. If CWA is to be applied to military procurement, it is likely that tool support will be required to help ensure that the process of modelling is understandable, and that the tool support may need to be based on a version of CWA with terminology specifically tailored to CF procurement.

- **The function of blank boxes in CWA models.** In our discussions about the application of CWA to requirements engineering, we suspected that ADS models and Decision Ladders done in the requirements phase may include system structures or operations that cannot be consistently or completely described. For example, the actual physical form of a system may not need to be prescribed in the requirements (which will lead to blank boxes in the physical form level of an ADS), or the full set of activators to a decision-making process may be unknown or only possible to define during the implementation phase (leading to an underspecified Activation box in the Decision Ladder). It is possible that these blank boxes will be able to help in identifying and bounding the unknowns of a procurement project.

- **CWA and scenarios.** Previous work (Torenvliet & Jamieson, 2007) has identified the potential for the ADS to support the development of scenarios that exercise relevant aspects of the work domain. While this work was performed in the context of a detailed analysis of crewing levels for a new naval platform, it is possible that it could be extended to support the development of better, more comprehensive scenarios for CBP or operational requirement development.

- **Potential for using ConTA as a point-of-departure for CWA.** Naikar, Moylan, and Pearce (2006) have produced helpful guidance on the application of ConTA that includes the concept of *work situations* and have proposed a question-based annotation method that can be more consistently interpreted across situations (Elix & Naikar, 2009). While the ADS can be difficult to understand because it treats human work in an actor- and event-independent way, ConTA has historically been easier to grasp because it is only actor-independent, and not event-independent. The addition of work situations to ConTA emphasized the event-dependent nature of this analysis, which could make this phase of CWA even more accessible to CF personnel.

- **Challenges with the Decision Ladder.** Even though ConTA is the most accessible of the CWA techniques, the visual form of the Decision Ladder can still be overwhelming to novices. There is potential to simplify this modelling tool.[8]

- **The Strategies Analysis phase of CWA may be difficult to apply in the context of CF procurement.** Strategies are artefacts of interactions between the work domain and the work support being designed. It is likely that this type of analysis is so dependent on the details of the way that work support is designed that it will be difficult to apply in the context of procurement. Investigating other phases of CWA is likely to have a higher return.

- **Position of SOCA within CWA.** Since Vicente's (Vicente, 1999) formulation of CWA, SOCA has been widely viewed as a discrete phase of CWA, but there may be some benefit

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[8] Gavan Lintern is currently developing a paper on this topic.

in returning to Rasmussen's (Rasmussen, et al., 1994) conception of it as a phase running in parallel with the other four phases of CWA. The concept that emerged at our meetings was of dealing with high-level social organization issues during Work Domain Analysis, and then progressing through increasingly detailed levels through ConTA, Strategies Analysis, and Work Competencies Analysis.

- **Non-hierarchical work organizations.** Especially in the context of network-centric warfare, the traditionally hierarchical structure of military organizations seems to be opening up to include increased cooperation between peers in different organizational units. Currently many of the changes in an organization's structures evolve through interactions with new systems and with allied forces using similar systems. A constraint-based perspective on collaboration may help to inform the development of team structures in this context.

- **CWA and crewing issues.** CWA has already been successfully applied to the development of a simulation model to test hypotheses about crewing levels in the context of damage control on a future naval platform (Coates & Cooper, 2009; Torenvliet, Coates, & Jamieson, 2008; Torenvliet & Jamieson, 2007; Torenvliet, Jamieson, & Cournoyer, 2007). There is potential to extend this work so that it serves as a better starting point for the application of military judgment to the setting of crewing levels.

- **Worker competencies analysis and CF Military Occupation Codes (MOCs).** The CF's MOCs contain information on the competencies that personnel in each position in the CF are expected to possess, and so the MOCs form a database of worker competencies information. DRDC has already done some work to understand how MOCs could be integrated with network simulations, and there is potential to expand this capability under Project 14dj.

3 Research opportunities

3.1 Introduction

The purpose of this section is to present the research questions that were raised through our review of CF procurement (Section 2.2) and current practice in requirements engineering and options analysis (Section 2.3), and through our discussions of CWA (Section 2.4). This section first presents the questions and research topics that were raised during our discussions, and then distils a number of proposals for specific research projects from these questions.

3.2 Research questions

3.2.1 Related to CF procurement

Our review of the CF procurement process has highlighted a number of important questions in the context of Project 14dj. These questions are listed below along with the section of the report that motivates them.

1. **Section 2.2.2 - High-level overview of the CF procurement process – How can M&S techniques assist in the application of the DNDAF?** DNDAF views are being promoted as a common modelling language for CF procurement projects, especially projects that have an information technology component. There seems to be an opportunity to supplement DNDAF methods, especially at the level of operational views, with results and representations from HF modelling techniques. An important question for DRDC in the context of Project 14dj is whether there is an opportunity for HF modelling techniques to assist in the application of the DNDAF.

2. **Section 2.2.2 - High-level overview of the CF procurement process - How can M&S techniques be tailored to an environment that is perceived to be chronically under-staffed and under-resourced?** M&S techniques are often perceived to be costly, both in terms of resources and time. An important question for DRDC to address in the context of Project 14dj is just how M&S can be used to deliver rapid results at a level of detail relevant to the context in which they are being applied.

3. **Section 2.2.2 - High-level overview of the CF procurement process - How can M&S techniques be tailored to provide risk reduction?** If the current culture in CF procurement is to favour risk reduction over detailed analysis, an important question for DRDC in the context of Project 14dj is how M&S techniques can be tailored to identify and analyse areas of high risk.

4. **Section 2.2.2 - High-level overview of the CF procurement process – What phases of the procurement process can be best addressed by M&S techniques?** The overview of the procurement process in this document was informed by SME input and a review of a collection of procurement documents. An important question for DRDC in the context of Project 14dj is how input from a larger pool of SMEs involved in current or recent

procurement projects (e.g., JUSTAS, MHP, HMCCS, Fixed-wing SAR, etc.) could provide better information as to where the CF perceives problems in the procurement process. This perspective could lead to more robust insights about the phases of procurement that can be best addressed by M&S techniques.

5. **Section 2.2.2 - High-level overview of the CF procurement process - General – How can M&S techniques provide a context for the application of best military judgment?** In Section 2.2.1, we quoted the Strategic Capability Roadmap (Chief of Force Development, 2008b) as being approving of the application of best military judgment over the use of formal models. Immediately following that quote is the following: "…the solution provided by the software model provided a starting point for discussion… (p. 52)." An important question for DRDC in the context of Project 14dj is how M&S techniques can be developed that provide insights that can function as the starting point for discussion.

6. **Section 2.2.4 –Capability-based planning – How can M&S techniques assist in the development of scenarios?** The CBP process relies heavily on the development of scenarios to develop an understanding of future capability requirements. It already includes guidelines for the development of scenarios; however, an important question for DRDC in the context of Project 14dj is whether or not there is any potential for modelling techniques to increase the quality of these scenarios.

7. **Section 2.2.5 –Operational requirements development – How can M&S techniques provide frameworks to assist in considering the full breadth of concerns when developing operational requirements?** An important question for DRDC in the context of Project 14dj is to assess if M&S techniques can provide structure to the development of operational requirements that will help to ensure that they are based on the full breadth of applicable concerns.

8. **Sections 2.2.5 - 2.2.7 – Operational requirements through to technical requirements and implementation – How can M&S techniques help to convert the tacit knowledge and assumptions behind requirements into explicit knowledge in requirements?** Requirements in one phase should not be based on tacit knowledge and assumptions that may not be shared or understood by personnel interpreting the requirements in the next phase. Since M&S techniques typically make use of naïve investigators to characterize a work context and so help to identify tacit knowledge and assumptions, an important question for DRDC in the context of Project 14dj is to assess whether formal modelling techniques applied by naïve investigators can assist in identifying tacit knowledge and assumptions for better inclusion in requirements.

9. **Sections 2.2.6-2.2.7 – Technical requirements and Implementation – How can M&S techniques help in bridging the gulf between the problem space and the solution space?** If it is true that CF personnel develop requirements around a mental model of an assumed solution, an important question for DRDC in the context of Project 14dj is whether or not modelling techniques can help operators to externalize their mental model of the assumed solution for critique and correction by others, and whether or not this would assist in ensuring that requirements were not unduly structured around an assumed solution.

10. **Overall – How can DRDC become more tightly engaged in procurement projects to be able to advocate for appropriate inclusion?** Outside of the technical questions pertaining specifically to M&S techniques, once DRDC has identified ways to have significant impact on the procurement process as per the questions above, an important question for DRDC in the context of Project 14dj will be to investigate how to become more tightly engaged in especially the early phases of procurement projects so that appropriate research efforts can be planned for up front, rather than carried out reactively.

3.2.2 Related to the literature on requirements engineering and options analysis

The following is a list of some potential research questions related to the literature review of requirements engineering and options analysis:

11. **How can requirements be posed within the important context of *why* and *how* (where relevant) without polluting the measurability and testability of requirements?** Addressing this question will ensure that any contributions of Project 14dj to the development of requirements respect the criteria for requirements set by current systems engineering and software development practice, while at the same time improving them.

12. **How can M&S techniques support a more efficient application of best military judgment?** If M&S techniques can be proposed that make the jobs of operators and engineers involved in requirements engineering and options analysis easier, they will be more readily adopted by the CF.

13. **How can M&S techniques support the development of measurable and testable criteria for human performance?** M&S techniques have an inherent focus on Measures of Effectiveness and Measures of Performance, and this focus could assist in the development of human-related requirements that are posed in the same language of measurability and testability as other system requirements.

3.2.3 Related to CWA

The following is a list of some potential research questions related to the application of CWA to requirements engineering and options analysis in CF procurement:

14. **Can WDA help to make explicit the implicit functional models and assumed implementations of the requirements engineering process, and will this help to mediate the effect of tacit knowledge and unstated assumptions on requirements development?** Addressing this question could help the CF to develop requirements that do not suffer from the interpretation challenges imposed by tacit knowledge and unstated assumptions, that include a more thorough consideration of human performance and decision-making factors, and that have a greater likelihood of including consideration of all relevant factors.

15. **Can the ADS help to provide requirements in their context, and help to mediate the effect of tacit knowledge and unstated assumptions on requirements development?** Including ADS models as a common visualization to support requirements documentation

may help to present requirements in their context. When authoring or reading requirements, this may help to clarify the presence of tacit knowledge or unstated assumptions.

16. **Can a tailored version of CWA and a tool to support its application be developed to make CWA more accessible to personnel involved in CF procurement?** Development of a tailored version of CWA relevant to CF procurement and of tool support for that version of CWA may be necessary preconditions to successfully applying CWA to CF procurement. A number of tools have already been developed by CWA researchers to support the application of CWA (for example, the Work Domain Analysis Workbench (Sanderson, Eggleston, Skilton, & Cameron, 1999) or the CWA tool by researchers at Brunel University[9]), and these tools could potentially be refined and extended for this purpose. Alternatively, work to resolve this question may identify that a fully new tool should be developed.

17. **Can CWA help to identify and bound the unknown aspects of a procurement project?** One of the major causes of cost overruns in major Crown procurement projects is incomplete requirements. If CWA can be developed as a tool to support the identification and bounding of unknown aspects of a procurement, aspects of the requirements definition that are incomplete may be identified earlier. Even if they cannot be resolved, the unknowns can be bounded and contingency resources can be allocated.

18. **Can CWA, and especially the ADS, assist in the development of more rigorous scenarios in the CBP and operational requirements development phases?** It is not clear that there is currently any structured means of assessing the completeness of the scenarios that are used for CBP and operational requirements development. CWA, and especially the ADS, show promise to support evaluations of scenario completeness, and it could be useful to investigate this promise further.

19. **Can ConTA, with the addition of consideration of work situations, be used as a point-of-departure for CWA?** If the addition of work situations to ConTA increase the accessibility of this phase of CWA, should ConTA be promoted as the starting point for the application of CWA to CF procurement?

20. **Can the visual form of the Decision Ladder be improved?** Since the visual form of the Decision Ladder may be overwhelming to novices, can the visual form of this modelling tool be improved to make it easier to read and apply?

21. **How can SOCA be re-cast in parallel with the other four phases of CWA, and is there any potential for this to make the application of CWA to CF procurement easier and more relevant?** There is an opportunity for some theory-based research (potentially with a university partner) to revisit the position of SOCA within CWA.

22. **What is the potential for CWA to inform the development of team-structures for systems in the context of network-centric warfare?** SOCA is one of the lesser exercised parts of CWA, but its potential for helping to develop team structures could help in the developing ConOps for new systems that anticipate the effects of the new systems on team structures, and so overcome at least a portion of the task-artefact cycle.

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[9] See http://www.brunel.ac.uk/about/acad/sed/sedres/dm/erg/cwa.

23. **Can the current technique for developing simulation models for assessments of crewing levels be extended to better support CF procurement questions?** There is potential to extend the work done to develop a network simulation of crewing issues (Coates & Cooper, 2009; Torenvliet, et al., 2008; Torenvliet & Jamieson, 2007; Torenvliet, et al., 2007) to be more useful within the context of procurement. This could involve refining the model to allow it to address a broader range of crewing issues, but could also include working with CF sponsors who are involved in setting initial targets for crewing levels and refining them as a project progresses to see how network-based simulations of crewing levels could be developed that use the data available at each decision point.

24. **Can the existing work to integrate MOCs with network simulations be extended, and can it be done in the context of the Worker Competencies Analysis phase of CWA?** Extending DRDC's work to integrate MOCs with network models could increase the coherence between network modelling and the fourth phase of CWA.

3.3 Research proposals

The purpose of this section is to propose five specific research projects that could be pursued by Project 14dj. These proposals follow from and consolidate the research questions documented in Section 3.2. For each proposal, a preliminary research objective has been developed, and links to the research questions motivating that research proposal are provided.

3.3.1 Proposal 1 – Application of CWA and M&S to the development of operational requirements

Objective. To develop an approach to applying CWA and M&S to the development of operational requirements for CF procurement.

Approach. The objective will be achieved by working with an in-progress test procurement project embarking on the phase of operational requirements development. The research will be conducted in the context of the selected procurement project to develop approaches to applying CWA and M&S techniques to assist in the development of operational requirements. Work will include:

- **High-level project review.** The SCR document from which the selected procurement project originated will be reviewed to gain an understanding of the capability deficiency and how that deficiency has been positioned in the context of the future battle-space.

- **ADS model development.** Appropriate ADS models to capture operators' understanding of the work domain should be developed. Knowledge elicitation to develop the ADS should focus on identifying tacit knowledge and unstated assumptions so that these types of information can be represented in the models, as appropriate. The ADS model should be aimed at the development of system-level operational requirements.

- **Scenario development.** The ADS developed in the previous work item should be used as a basis for assessing the scenarios created by operational personnel, or as a basis for assisting operational personnel in developing scenarios. Attention should be paid to methods for using the ADS to assess the breadth of scenarios.

- **ConTA.** Naikar et al.'s (2006) guidance on the use of work situations to structure the development of ConTAs should be applied to the procurement project as relevant to help in developing system-level operational requirements. Knowledge elicitation to develop the Decision Ladders should focus on identifying tacit knowledge and unstated assumptions so that these types of information can be represented in the models, as appropriate. New research findings in Decision Ladder representation should be used in this work, as well as any other possible efforts to ensure the Decision Ladders are represented in a form that is meaningful to CF personnel.

- **Requirements review.** At the conclusion of these work items, the findings and models from the previous work items should be used to conduct a review of the actual operational requirements produced by project staff. This review should focus on identifying potential problems with the requirements in terms of their future use for the development of technical requirements, including: incompleteness, inconsistencies, unstated assumptions, and meaning built on tacit knowledge. Alternatives should be posed that, while still meeting the criteria of being measurable and testable, also provide context for each requirement. If possible, this review should be conducted in cooperation with project staff, and findings should be reviewed by project staff.

- **Methodological contribution.** At each stage, the steps used to develop the various analyses should be developed into an initial version of a CWA manual for CF procurement. The methodological development should focus on preparing a manual that could be understood, and potentially used, by CF personnel. The contents of the manual should focus on the development of an efficient process that provides flexibility to identify and address only the most significant project risks. Comments should be made on the potential for CWA modelling to identify and bound project unknowns. Finally, comments should also be made on the form that requirements should take if they are to be measurable and testable while also providing appropriate context.

Rationale. This research proposal has been developed around the first three phases of CWA because those phases are the best understood and show the best potential for systematization in the context of CF procurement. An in-progress project was chosen over an already completed project because (a) since this work should provide real benefits to a project sponsor, working with an in-progress project should help in securing funding for this work; and, (b) an in-progress project is a more realistic context than a completed project. Finally, the development of operational requirements was selected as a project context because this phase of procurement has typically been found by DRDC scientists to be the most amenable to research projects.

Linkages. This research will address the following research questions from Section 3.2:

- 2 – How can M&S techniques be tailored to an environment that is perceived to be chronically under-staffed and under-resourced?

- 3 – How can M&S techniques be tailored to provide risk reduction?

- 6 – How can M&S techniques assist in the development of scenarios?

- 7 – How can M&S techniques provide frameworks to assist in considering the full breadth of concerns when developing operational requirements?

- 8 – How can M&S techniques help to convert the tacit knowledge and assumptions behind requirements into explicit knowledge in requirements?

- 9 – Technical requirements and Implementation – How can M&S techniques help in bridging the gulf between the problem space and the solution space?

- 11 – How can requirements be posed within the important context of why and how (where relevant) without polluting the measurability and testability of requirements?

- 14 – Can WDA help to make explicit the implicit functional models and assumed implementations of the requirements engineering process, and will this help to mediate the effect of tacit knowledge and unstated assumptions on requirements development?

- 15 – Can the ADS help to provide requirements in their context, and help to mediate the effect of tacit knowledge and unstated assumptions on requirements development?

- 17 – Can CWA help to identify and bound the unknown aspects of a procurement project?

- 18 – Can CWA, and especially the ADS, assist in the development of more rigorous scenarios in the CBP and operational requirements development phases?

- 19 – Can ConTA, with the addition of consideration of work situations, be used as a point-of-departure for CWA?

3.3.2 Proposal 2 – Cognitive task analysis of requirements engineering and options analysis in CF procurement

Objective. To develop an understanding of the types of M&S and HF support that could be developed to support CF procurement, by conducting a cognitive task analysis of requirements engineering and options analysis in CF procurement.

Approach. The objective will be achieved by working with CF personnel with experience in requirements development and options analysis during the various phases of procurement to understand how they did their work, the challenges they encountered, the elements that work well, and the potential for improvements. Work will include:

- **Review of the phases of CF procurement.** The phases of CF procurement should be reviewed to determine the types of CF personnel to interview, and the broad categories of information to elicit. Ideally, the project team should include ex-CF personnel with experience in all phases of procurement to help in locating CF personnel to interview, to help in narrowing down the categories of information to elicit, and to serve as a domain interpreter.

- **Identification of interviewees.** The appropriate CF personnel should be identified and contacted to arrange interviews. We expect that interviews will need to be conducted with up to seven different groups of subject matter experts (one group with experience in CBP; one group from each environment with experience in operational requirements development; and, one group from each environment with experience in technical requirements development).

- **Development of a knowledge elicitation approach.** Once interviewees have been identified, a detailed knowledge elicitation approach should be developed for each group of

interviewees. While we expect that most interviews will need to be conducted in a group, it could also be beneficial to conduct a more ethnographic form of knowledge elicitation, with project team members participating in a series of procurement activities at each phase.

- **Knowledge elicitation.** After the knowledge elicitation approach has been approved, the knowledge elicitation activities should be conducted. Team debriefs should be held after each session with data consolidation sessions to be held as appropriate to aggregate results.

- **Data reduction and validation.** The data from the interviews should be reduced into sets of observations and implications. These should be validated with the CF personnel who participated in the interviews. The data validation should also include discussions with CF personnel about their ideas on opportunities for reducing overall procurement risk and for working more efficiently, and how M&S techniques could support this.

- **Identification of opportunities for M&S and HF support.** Finally, the validated observations and implications should be reviewed in a workshop of interested parties to determine the opportunities for M&S and HF support in procurement that result from the data.

Rationale. This research proposal is relevant because it will supplement the observations and conclusions of this scoping study with data from actual CF experiences with procurement. This could help to identify high priority opportunities for M&S and HF techniques, especially to assist in reducing program risk and working more efficiently with scarce resources.

Linkages. This research will address the following research questions from Section 3.2:

- 2 – How can M&S techniques be tailored to an environment that is perceived to be chronically under-staffed and under-resourced?

- 3 – How can M&S techniques be tailored to provide risk reduction?

- 4 – What phases of the procurement process can be best addressed by M&S techniques?

- 5 – How can M&S techniques provide a context for the application of best military judgment?

- 10 – How can DRDC become more tightly engaged in procurement projects to be able to advocate for appropriate inclusion?

- 12 – How can M&S techniques support a more efficient application of best military judgment?

3.3.3 Proposal 3 – Development of a CWA tool to support CF procurement

Objective. To develop the requirements for a software tool to standardize the application of CWA to CF procurement.

Approach. This project will follow from the results of the research proposal described in Section 3.3.1 (*Proposal 1 – Application of CWA and M&S to the development of operational requirements*), and will implement the guidance in the CWA Manual developed in that research as a software tool. We expect that the first phase of this work will develop a tool to support WDA

and ConTA, and subsequent phases of work will add in support for the remaining phases of CWA. This tool could be developed as a stand-alone application, or as a new module for an existing tool. Work will include:

- **Review of the CWA manual.** The CWA manual developed in the prior research will be reviewed to gain an understanding the modifications that it proposes to the canonical methods of CWA in the literature.

- **Review of other CWA and M&S tools.** Existing CWA tools (the Work Domain Analysis Workbench and the Brunel University CWA tool) will be reviewed. This review will note their features, functionality, strengths, and weaknesses. In addition, the review should also include existing M&S tools currently held by DRDC or used by the requirements engineering community, with a view to their suitability as a platform for integrating a CWA tool for CF procurement.

- **Requirements development workshop.** A workshop will be conducted to develop the requirements for a CWA tool to support CF procurement. This workshop will draw on the results of the previous reviews, and will aim to generate a list of high-level requirements for the tool, and will include considerations of how this tool could be integrated with other current DRDC tools (e.g., IPME). A final output of the workshop will be a comparison between the high-level requirements generated and the existing CWA tools to develop a recommendation to start tool development from scratch or to extend an existing tool.

- **Development of a high-level interface design.** The interface architecture for the tool will be developed and user tested with knowledgeable subject matter experts, as possible. Once the interface architecture has been developed, a paper-based or low-fidelity software-based prototype of the overall application will be developed for user testing and redesign.

- **Development of a high-level application architecture.** The high-level user interface design will be used to develop a high-level application architecture. High-level tradeoffs between the proposed interface design and the application architecture will be performed at this time.

- **(Iterative) detailed design and implementation.** Once the high-level interface design and application architecture are approved, the detailed design and implementation will proceed. This should be done using an iterative process that confronts the highest-risk application elements (from a design or implementation perspective) first, and that includes appropriate user testing and redesign.

The actual way in which the work items of this project are organized may depend on whether this work is conducted by DRDC or in cooperation with a third-party contractor, and on the level of funding available. If only a small amount of initial funding can be procured, it may be wise to perform this work in two phases (for example, requirements / interface design and application design and implementation).

Rationale. This research proposal follows directly from the objectives of Project 14dj.

Linkages. This research will address the following research questions from Section 3.2:

- 16 – Can a tailored version of CWA and a tool to support its application be developed to make CWA more accessible to personnel involved in CF procurement?

- 20 – Can the visual form of the Decision Ladder be improved?

3.3.4 Proposal 4 – Applying SOCA to CF procurement projects

Objective. To re-engineer the SOCA phase of CWA to provide a framework that develops requirements that specifically relate to organizational and teaming needs.

Approach. This objective will be achieved by working with a team of DRDC personnel and CWA experts to analyse the most recent developments in SOCA. Several team and organizational modeling approaches will be explored for their potential to contribute to SOCA. SOCA as it currently exists should be challenged and reworked with a view to substantially revising this analysis and its positioning within the CWA framework. In the final phase of this project, the revision of SOCA should be tested within a CF environment to determine new technology requirements. These requirements should be examined against existing CF procurement requirements to evaluate the feasibility of SOCA to contribute to CF procurement projects. Work will include:

- **Review of SOCA.** The original intent of SOCA will be reviewed. As well recent efforts to apply CWA to team and social environments will be reviewed for their potential role in a revised SOCA.

- **Development of a revised SOCA.** In consideration of the intent of SOCA, and with current tools for team and social-organizational analysis, a new SOCA will be developed. This SOCA may need to be positioned differently within the CWA process than the current analysis.

- **Test of the revised SOCA.** Within a CF environment that has teaming and social-organizational collaboration needs, the revised SOCA should be field-tested to confirm the approach. The result of this approach should be a list of social-organizational and teaming requirements within that environment. The revised SOCA should also be assessed for the practicality of the approach in terms of learnability, resources required and time to generate requirements.

- **Evaluation against other requirements methods.** To establish or to challenge the value of the revised SOCA, the requirements from stage 3 will be compared against requirements from an existing requirements exercise to determine whether the revised SOCA has the potential to generate richer and more useful teaming and organizational requirements.

Rationale. This research proposal is relevant because it expands the tools available to determine teaming and social-organizational requirements. Most of the current tools that examine teams or organizations do not have an engineering perspective. As a result they do not address how new technologies could impact teams or organizational behaviour and therefore, are not appropriate for requirements generation. With the increase of network-centric environments, team structure requirements and social-organizational requirements are critical to understand.

Linkages. This research will address the following research questions from Section 3.2:

- 21 – How can social organization and cooperation analysis be re-cast in parallel with the other four phases of CWA, and is there any potential for this to make the application of CWA to CF procurement easier and more relevant?

- 22 – What is the potential for CWA to inform the development of team-structures for systems in the context of network-centric warfare?

3.3.5 Proposal 5 – Extension of DRDC's crewing effectiveness network model

Objective. To extend the DRDC crewing effectiveness network model to better support potential CF procurement questions around crewing levels, to develop this model into a more generic crewing effectiveness tool, and to investigate if data from the MOCs can be used as a source for Worker Competencies data in the model.

Approach. This work is recommended to commence after the work related to proposals 3.3.1 (*Proposal 1 – Application of CWA and M&S to the development* of operational requirements) and 3.3.2 (*Proposal 2 – Cognitive task analysis of requirements engineering and options analysis in CF procurement*) is complete, so that insights especially about how M&S tools for supporting the application of best military judgment can inform the work approach. Work items will include:

- **Requirements investigation - general.** The results of the related proposals 3.3.1 and 3.3.2 will be reviewed to develop any insights from that research as they relate to the extension of the crewing effectiveness model. We also recommend that interviews be held with Naval Subject Matter Experts to review with them the possible outputs of the crewing effectiveness model and to learn from them their opinions of how such models could support decisions pertaining to crew size at the various phases of procurement, and how these decisions contribute to the development of requirements.

- **Requirements investigation – integration of MOCs.** A separate requirements development activity should be conducted to propose ways that data from the MOC database could be integrated with IPME's human performance model, to allow for the specification of crews for the model that have different capabilities.

- **Requirements setting.** A team workshop should be held to review the results of the two investigations and to set the requirements for an updated version of the crewing effectiveness model, and for the development of this model into a more generic crewing effectiveness tool.

- **Implementation and testing.** The tool will be implemented as per the requirements, and a test experiment will be run to verify and validate the types of results that can be produced by the tool.

- **Lessons learned.** Once the tool has been implemented and tested, a lessons learned workshop should be conducted to assess the appropriateness of the tool for supporting decision making (and especially the application of best military judgment) in the context of crewing decisions, and the appropriateness of similar tools for supporting decision making (and especially the application of best military judgment) in the context of military procurement in general.

Rationale. This project follows from previous DRDC research as informed by the implications of this scoping study, and holds promise to demonstrate how formal models can support the application of best military judgment.

Linkages. This research will address the following research questions from Section 3.2:

- 5 - How can M&S techniques provide a context for the application of best military judgment?

- 13 – How can M&S techniques support the development of measurable and testable criteria for human performance?

- 23 – Can the current technique for developing simulation models for assessments of crewing levels be extended to better support CF procurement questions?

- 24 – Can the existing work to integrate MOCs with network simulations be extended, and can it be done in the context of the Worker Competencies Analysis phase of CWA?

3.4 Project sequencing

Although the research proposals presented in Sections 3.3.1 - 3.3.5 can each be treated as stand-alone projects, there will be a benefit in carrying them out in a specific sequence, as shown in Figure 9, below. If this sequence is followed, the insights about the CF procurement process gained from Proposals 1 and 2 (which can be viewed as a requirements analysis phase) will be able to influence the methods chosen for the research of Proposals 3 and 5 (which can be viewed as an implementation phase).

We recommend that Proposal 5 be conducted at any point in the two years remaining in Project 14dj. The nature of this research is such that it would be beneficial to develop it with a university partner, and the two-year time-frame allocated matches with the typical duration of a Master's program, or with a portion of a Doctoral program.
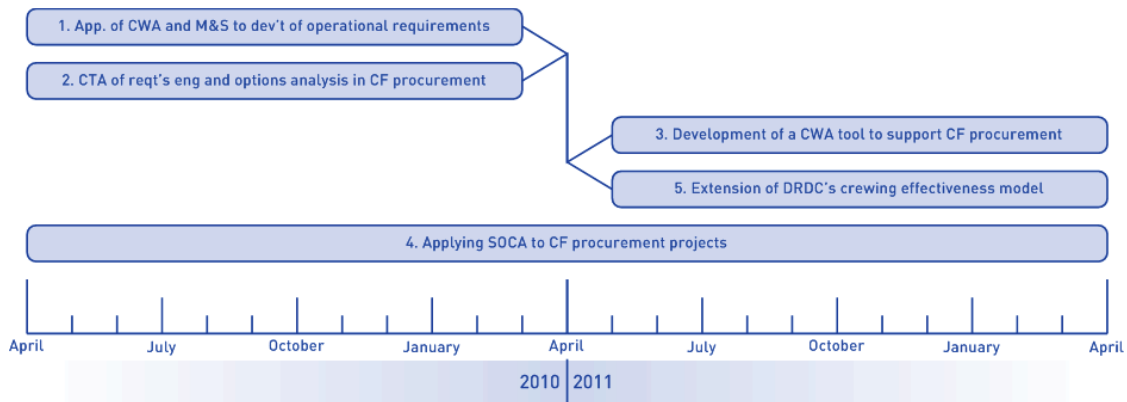
Figure 9: Proposed research phasing.

3.5 Research question coverage

The research proposals presented in Sections 3.3.1 - 3.3.5 cover every research question raised in Section 3.2, except for question 1, "How can M&S techniques assist in the application of the DNDAF?" While this remains a relevant research question, it did not fit easily into any of the research proposals we have presented.

If the DNDAF is a research area that DRDC would like to pursue, we recommend that work items to more fully investigate challenges and opportunities in the application of the DNDAF (that could potentially be resolved by M&S techniques) be included in Research Proposal 1 or 2. Some promising work has been done to add Human Views to the United Kingdom's counterpart to DNDAF, the Ministry of Defense Architectural Framework (MODAF) (Bruseberg, 2008; Bruseberg & Fletcher, 2008; Lintern & Bruseberg, 2007) as well as to architectural frameworks for NATO countries in general (Handley & Smillie, 2008) and Canada in particular (NATO RTO HFM-155 Human View Workshop, 2009), and it could be useful to review this work to understand its relevance within the context of the DNDAF.

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4   Conclusions

In this report, we have presented DRDC with an R&D roadmap for Project 14dj, "Modelling and Simulation for Requirements Engineering and Options Analysis" that includes five specific research proposals:

- Proposal 1 – Application of CWA and M&S to the development of operational requirements

- Proposal 2 – Cognitive task analysis of requirements engineering and options analysis in CF procurement

- Proposal 3 – Development of a CWA tool to support CF procurement

- Proposal 4 – Applying SOCA to CF procurement projects

- Proposal 5 – Extension of DRDC's crewing effectiveness network model

These research proposals are based on 24 research questions that were derived from reviews of the CF procurement process and current requirements engineering and options analysis practice, and an expert brainstorming session on the application of CWA to requirements engineering and options analysis. Each research proposal has been presented with an objective and an overview of the work items that should be accomplished to reach the stated objectives. The research proposals have been presented as an overall research program that includes an initial phase of requirements analysis followed up by a phase of modelling and tool implementation.

Following the research program we have developed will provide DRDC with the following benefits:

- **Understanding of the procurement process.** Especially with the research of Proposals 1 and 2, DRDC will gain a strong understanding of the CF procurement project. In addition to the benefits for the follow-on research in Project 14dj, this understanding could help DRDC as a whole to better target other elements of its research to have an impact on the procurement process.

- **Full coverage of CWA.** The potential for all five phases of CWA to contribute to the CF procurement process will be explored, which will result in applied and theoretical contributions.

- **Tool development.** This research program could provide DRDC with a tool for conducting CWA that is integrated with other tools used within the DRDC community, and with a tool for assisting the CF in determining crewing levels for future platforms. These are important steps toward developing a cohesive M&S framework for DRDC.

- **Formal modelling.** Finally, this research program will advance DRDC's understanding of how to use formal modelling methods (such as IPME) to provide results that have the potential to inform the application of best military judgment in procurement projects.

More broadly, if these research projects are successful, the CF should benefit from an overall reduction of risk in the procurement cycle. This should lead to more predictable procurement projects that are better able to provide the CF with the capabilities required to meet their strategic objectives.

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References

Bisantz, A. M., Roth, E. M., Brickman, B., Gosbee, L. L., Hettinger, L., & McKinney, J. (2003). Integrating cognitive analyses in a large-scale system design process. *International Journal of Human-Computer Studies, 58*, 177-206.

Bruseberg, A. (2008). Human Views for MODAF as a Bridge Between Human Factors Integration and Systems Engineering. *Journal of Cognitive Engineering and Decision Making, 2*, 220-248.

Bruseberg, A., & Fletcher, G. (2008). *The Human View Handbook for MODAF*. Bristol, UK: MOD HFI DTC.

Bubenko, J. A. (1995). *Challenges in requirements engineering*. Paper presented at the Proceedings of the Second IEEE International Symposium on Requirements Engineering.

Burns, C. M., & Hajdukiewicz, J. R. (2004). *Ecological Interface Design*. Boca Raton, FL: CRC.

Carroll, J. M., Kellogg, W. A., & Rosson, M. B. (1991). The task-artifact cycle. In J. M. Carroll (Ed.), *Designing interaction: Psychology at the human-computer interface* (pp. 74-102). Cambridge, England: Cambridge University Press.

Castro, J., Kolp, M., & Mylopoulos, J. (2002). Towards requirements-driven information systems engineering: the Tropos project. *Information Systems, 27*(6), 365-389.

Chalmers, B. A., Easter, J. R., & Potter, S. S. (2000). *Decision-Centred Visualisations for Tactical Decision Support on a Modern Frigate*. Paper presented at the Proceedings of 2000 Command and Control Research and Technology Symposiu.

Cheng, B. H. C., & Atlee, J. M. (2007). *Research Directions in Requirements Engineering*. Paper presented at the 2007 Future of Software Engineering.

Chief of Defence Staff. (2008). *Canada First Defence Strategy*. Retrieved from http://www.forces.gc.ca/site/pri/first-premier/index-eng.asp.

Chief of Force Development. (2008a). *Capability Based Planning in Force Development*.

Chief of Force Development. (2008b). *Strategic Capability Roadmap Version 1.0*.

Coates, C., & Cooper, C. (2009). *Crewing effectiveness: Full-scale model development*. Toronto, Ontario: Defence Research & Development Canada - Toronto.

Crandall, B., Klein, G., & Hoffman, R. R. (2006). *Working minds: A practitioner's guide to cognitive task analysis*. Cambridge, MA: MIT Press.

Director Enterprise Architecture. (2009). *DND/CF Architectural Framework, Version 1.6 (Volumes 1-4)*.

Elix, B., & Naikar, N. (2009). *Designing safe and effective future systems: A new approach for modelling decisions in future systems with Cognitive Work Analysis*. Paper presented at the 8th Annual International Symposium of the Australian Aviation Psychology Association.

Feather, M., & Cornford, S. (2003). Quantitative risk-based requirements reasoning. *Requirements Engineering, 8*(4), 248-265.

Gilb, T., & Gilb, K. (2007). Evolutionary project management.

Gualtieri, J. W., Szymczak, S., & Elm, W. C. (2005). *Cognitive System Engineering-Based Design: Alchemy or Engineering*. Paper presented at the The Human Factors and Ergonomics Society 49th Annual Meeting.

Hagenaars, C. H. A. (2003). *An overview of the advisory functions on RNLN's ADCF*. Paper presented at the 13th International Ship Control Systems Symposium.

Halligan, R. J. (undated). Requirements quality metrics: The basis of informed requirements engineering management. Project Performance (Australia) Pty Ltd.

Handley, H. A. H., & Smillie, R. J. (2008). Architecture framework human view: The NATO approach. *Systems Engineering, 11*(2), 156-164.

Haskins, C. (Ed.). (2007). *INCOSE Systems Engineering Handbook, 3rd Edition*. San Diego, CA: International Council on Systems Engineering.

INCOSE Tools Database Working Group. (undated). *INCOSE Tools Database*: INCOSE.

Lintern, G. (2009). *The Foundations and Pragmatics of Cognitive Work Analysis: A Systematic Approach to the Design of Large-Scale Information Systems*. East St. Kilda's, Australia: Self-published.

Lintern, G., & Bruseberg, A. (2007). *Human Functional Analysis of Lean Staffing: Extensions to the Department of Defense Architecture Framework (DoDAF)*. Paper presented at the Seventeenth Annual International Symposium of the International Council On Systems Engineering (INCOSE).

Miller, C. A. (2004). *A playbook approach to variable autonomy control: Application for control of multiple heterogeneous unmanned air vehicles*. Paper presented at the FORUM 60, the Annual Meeting of the American Helicopter Society.

Miller, C. A., & Vicente, K. J. (2001). Comparison of Display Requirements Generated Via Hierarchical Task and Abstraction-Decomposition Space Analysis Techniques. *International Journal of Cognitive Ergonomics, 5*(3), 335 - 355.

Naikar, N., Hopcroft, R., & Moylan, A. (2005). *Work Domain Analysis: Theoretical Concepts and Methodology*. Fishermen's Bend, Victoria: Australian Government Department of Defence / Defence Science and Technology Organisation.

Naikar, N., Moylan, A., & Pearce, B. (2006). Analysing activity in complex systems with cognitive work analysis: concepts, guidelines and case study for control task analysis. *Theoretical Issues in Ergonomics Science, 7*(4), 371-394.

Naikar, N., Pearce, B., Drumm, D., & Sanderson, P. M. (2003). Designing teams for first-of-a-kind, complex systems using the initial phases of cognitive work analysis: case study. *Human Factors, 45*(2), 202-217.

Naikar, N., & Sanderson, P. M. (2001). Evaluating design proposals for complex systems with work domain analysis. *Human Factors, 43*, 529-542.

NATO RTO HFM-155 Human View Workshop. (2009). *The NATO Human View Handbook*.

Philbin, S. P. (2008). Bid management: A systems engineering approach. *The Journal of High Technology Management Research, 19*(2), 114-127.

Rasmussen, J., Pejtersen, A. M., & Goodstein, L. P. (Eds.). (1994). *Cognitive systems engineering*. New York: John Wiley & Sons.

Sanderson, P. M., Eggleston, R., Skilton, W., & Cameron, S. (1999). *Work Domain Analysis Workbench: Supporting Cognitive work Analysis as a Systematic Practice*. Paper presented at the Human Factors and Ergonomics Society 43rd Annual Meeting.

Torenvliet, G. L., Coates, C., & Jamieson, G. A. (2008). *Functional Modelling, Scenario Development, and Options Analysis to Support Optimized Crewing for Damage Control - Phase 3: Options Analysis*. Ottawa, Ontario: CMC Electronics.

Torenvliet, G. L., & Jamieson, G. A. (2007). *Functional Modelling, Scenario Development, and Options Analysis to Support Optimized Crewing for Damage Control - Phase 2: Scenario Development*. Ottawa, Ontario: CMC Electronics.

Torenvliet, G. L., Jamieson, G. A., & Cournoyer, L. (2007). *Functional Modelling, Scenario Development, and Options Analysis to Support Optimized Crewing for Damage Control - Phase 1: Functional Modelling (Revision A)* (Contract Report No. CMC Document 1000-1370 / DRDC Toronto CR 2006-090). Ottawa, Ontario: CMC Electronics.

van Lamsweerde, A. (2000). *Requirements engineering in the year 00: a research perspective*. Paper presented at the Proceedings of the 22nd international conference on Software engineering.

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

Vicente, K. J., & Rasmussen, J. (1992). Ecological interface design: Theoretical foundations. *IEEE Transactions on Systems, Man, and Cybernetics, 22*, 589-606.

Yeh, R. T. (1984). System development as a wicked problem. In D. E. Cooke (Ed.), *The impact of CASE technology on software processes* (pp. 15-29): World Scientific.

Yu, E. S. K. (1997). *Towards Modeling and Reasoning Support for Early-Phase Requirements Engineering.* Paper presented at the Third IEEE International Symposium on Requirements Engineering (RE '97), Annapolis, MD.

Annex A   Literature review of current requirements engineering practice

The following pages reproduce the slides summarizing the results of the literature review of current requirements engineering practice. These slides were presented at the project workshop held on 21-22 January 2010.

Modeling and simulation for Requirements Engineering and Options Analysis

Literature Review

Antony Hilliard

January 21, 2010

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1

Scope of Review

- Managing requirements after Canadian Forces have decided 'what they want'

- Managing requirements for socio-technical systems, typical of SORs/SOIs and RFPs

- Looking for 'peopleware' requirements and fit with DRDC Toronto's M&S specialties

- Not exhaustive: four days & 22 documents

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2

Organization of talk

1. Orientation to Literature

2. Perspectives on workshop topics

3. Previous CWA application to RE & OA

4. Wrap-up

Orientation to Literature

- Three main schools of practice, with differing principles, theories, and methods

1. Software Requirements Engineering

    – Bulk of literature, 1970s-present

2. Systems Engineering & Project Management

    – Longer history, Less journal publishing

3. Socio-technical systems / Cognitive Engineering

    – Smaller field of practice, less adoption

4

Table 1. Matrix Summarizing the State of the Art of Requirements Engineering   Cheng & Atlee, 2007

software

Requirements Tasks	Requirements Technologies		
	Notations	Methodologies, Strategies, Advice	Techniques, Analyses, Tools
Elicitation	Goals [19, 109, 173] Policies [18] Scenarios [1, 32, 47] Agents [106, 183] Anti-models [157, 166, 174] Nonfunctional requirements [28, 69]	Identifying stakeholders [152] Metaphors [133, 136] Persona [9, 34] Contextual requirements [33, 160] Inventing requirements [117]	Animation [84, 115, 170] Simulation [164] Invariant generation [93]
Modeling	Object models [89] Behavioral models [92, 167] Domain descriptions [11] Property languages [14, 50, 105] Notation Semantics [59, 120, 125, 163]	RE reference model [75, 77, 131] Model elaboration [169] Viewpoints [128, 155] Patterns [49, 54, 90, 99, 171] Modeling facilitators [6, 31, 72, 97, 129] Formalization heuristics [18, 67] Methodologies [15]	Model merging [147, 165] Model synthesis [3, 39, 107, 168, 182] Model composition [80]
Requirements Analysis		Negotiation [87] Aligning requirements with COTS [5, 144] Conflict management [143]	Linguistic analysis [16, 27, 176] Ontologies [95] Checklists [177] Consistency checking [58, 83, 123] Inspections [60, 132] Conflict analysis [25, 79] Obstacle analysis [114, 175] Risk management [62] Impact analysis [101] Causal order analysis [12] Prioritization [122] Variability analysis [74, 108, 110] Requirements selection [139, 159]
Validation & Verification	Model formalisms [22, 51]		Simulation [164] Animation [84, 115, 170] Invariant generation [93] Model checking [26, 55, 158] Model satisfiability [89]
Requirements Management	Variability modeling [21, 38, 140, 150]	Scenario management [2] Feature management [179] Global RE [44]	Traceability [30, 81, 146, 151] Stability analysis [23]

5

Orientation to Terminology

- **Requirements Engineering (8 definitions)**
  - Software field from 1970s-2000 defines narrowly
  - Later definitions often made in terms of methods

- **Options Analysis (4 definitions)**
  - Some view from perspective of bidding contractor
  - Can be conflated with design process

6

Orientation to Terminology

- Requirements
  - Why, what, or how?
- "Non-Functional" Requirements
  - Everything that can't be described in terms of inputs, behavior, outputs
- Modeling
  - Executable models vs. ontologies & representation
- Simulation
  - Usability testing and prototyping?

Perspectives: How are others…

1. Doing RE and OA today, and what are they trying to achieve?

2. Dealing with large numbers and varieties of requirements?

3. Anticipating & reducing task-artifact cycles?

4. Testing and validating performance metrics for options analysis?

5. Integrating Modeling & Simulation?

6. Failing…

Differing Priorities / Aspirations for RE

1. Software practitioners want:
   - Requirement formats that fit their workflow
   - Flexible, one-size-fits-all tools
   - To minimize costs & risk of programming re-work

2. Systems Engineers want:
   - To reach clear & binding consensus with clients
   - To quantify costs & effort of changing deliverable

3. STS / Cognitive Engineers want:
   - To deliver creative, effective design solutions

Managing many messy requirements

1. Little support / designer's intuition

2. Organize, sort, automate

   – Formal methods for functions in 'tidy' systems

   – Reductionism or just good structure?

3. Abstraction or aggregation

   1. Without ontology (NASA DDP)

   2. With goals / tasks (i*, KAOS)

   3. With practice-specific abstractions

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Envisioned worlds & Task-artifact cycle

- Not yet a pressing concern for practitioners

- Software approaches (UML & similar) are normative or descriptive

- Industry practitioners rarely design first-of-a-kind systems that can't be prototyped

- Goal-oriented approach assumes that actors and intentions will be invariant across artifacts

- Flagged as a future concern for software RE

Interest in & tools for Options Analysis

- When system options are closely coupled, side effects of component-level choices dominate

- Few methods for justifying choices

1. Metrics from anticipated effects (i*, KAOS)

2. Metrics from expert workshops (NASA DDP)

3. Metrics from 'risk & cost' guess & calculate

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Integrating Modeling & Simulation

- Did not find executable 'peopleware' M&S

- Software engineering M&S methods only work given environmental assumptions

- Integration of software, hardware, and peopleware modeling languages flagged as an open research question (Cheng & Atlee, 2007)

- Past CWA work complemented numeric simulation (Naikar & Sanderson 2001)

How does RE fail?

- Tension between technical & operational
- UML ignores 'non-functional' requirements, yet they then surface in validation & results CEL1
- Goal-oriented methods seem to not scale well
- Experts can easily judge components, but system-level effects not always linear
- Traditional justifications for CWA still apply

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Previous CWA application to RE & OA

- OA part of Acquisition work by Australian Defense Science & Technology Organization
  - Airborne Early Warning & Control
    - Tender selection (Naikar & Sanderson, 2001)
    - Team design (Naikar et al., 2003)
  - Unmanned Aerial Vehicles (Elix & Naikar, 2009)

Using WDA for Tender Evaluation

Using WDA for Tender Evaluation

Option A

Option B

Option C

5) Committee compares & ranks all WDA elements

6) Presentation to senior military staff
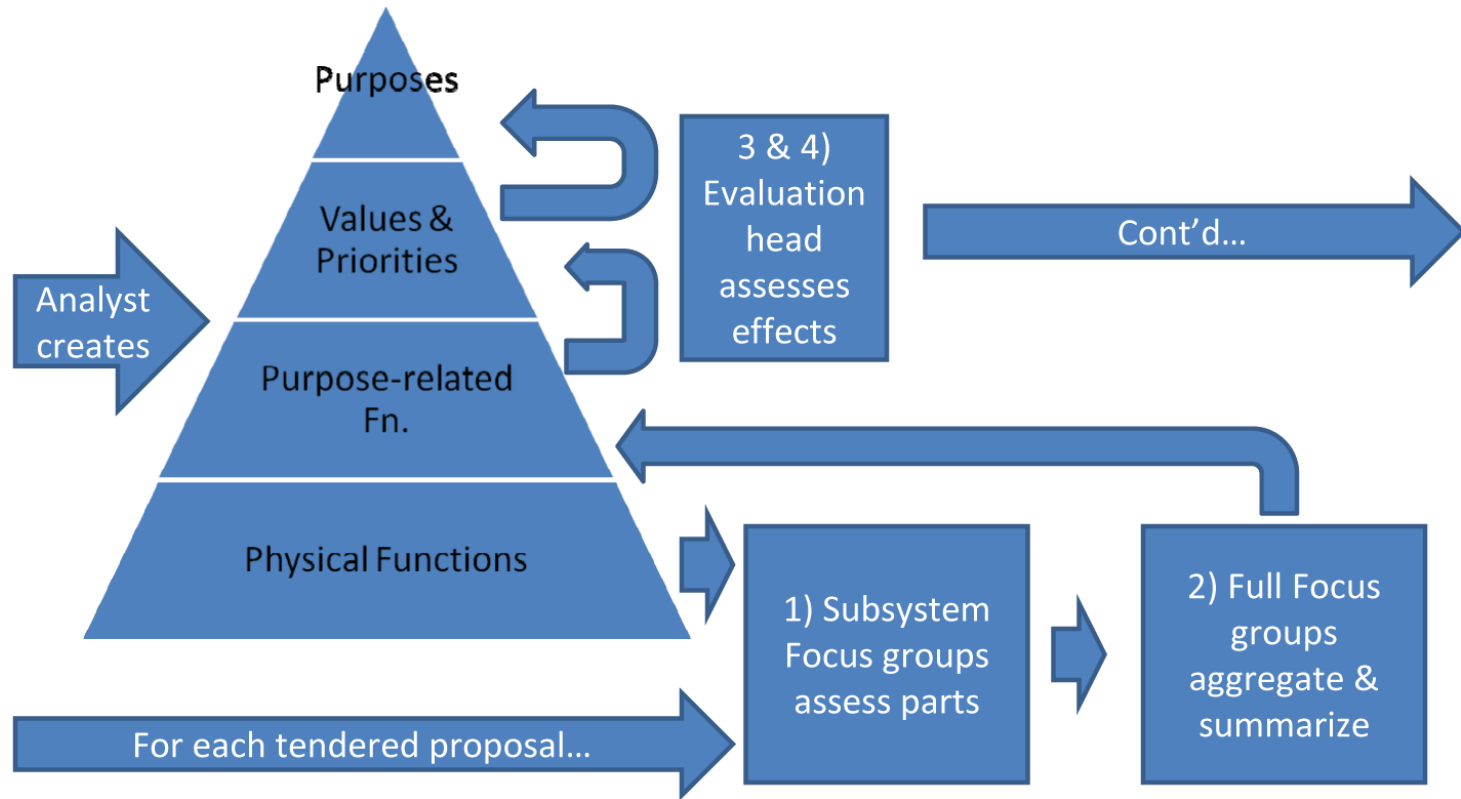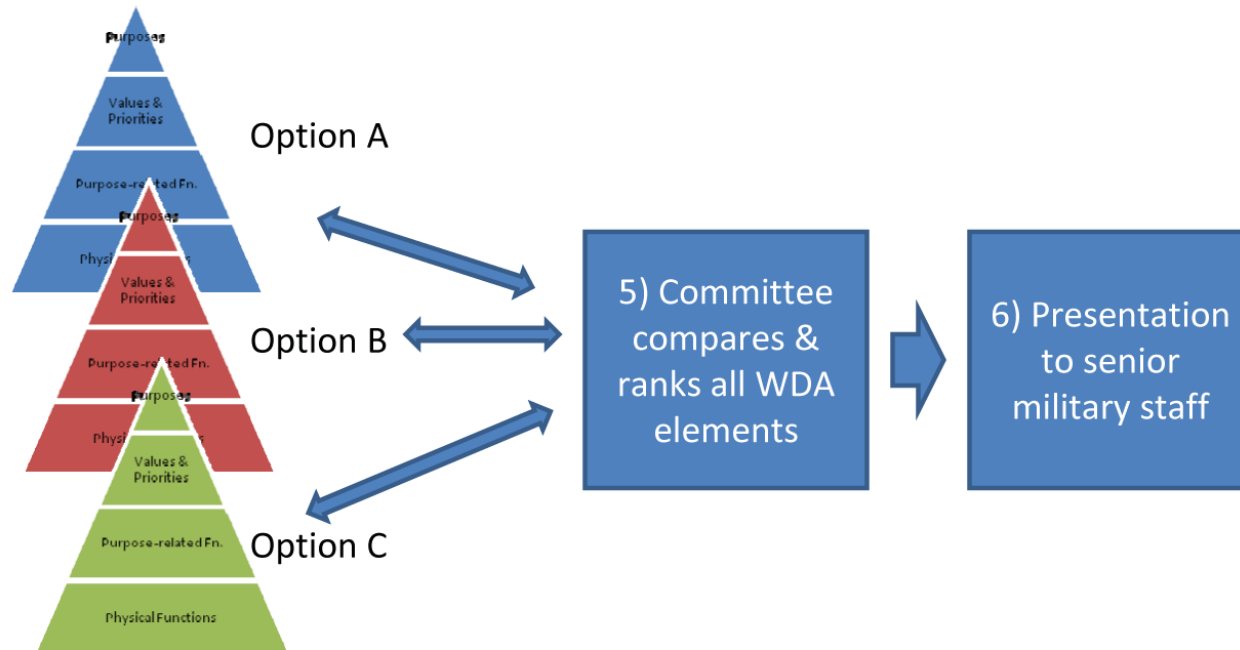
Using ConTA for Team Requirements

- Acquisition requirements depend on team size, organization, degree of multiskilling

- WDA re-used

- ConTA used to develop systematic scenarios

- Tabletop focus groups led through scenarios, for each permutation of team design options

- Judgments elicited & compared in WDA terms

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Dividing Electronic Support (ES) sectors
Identifying tracks of interest
Control of P3C

19
Naikar et al. 2003
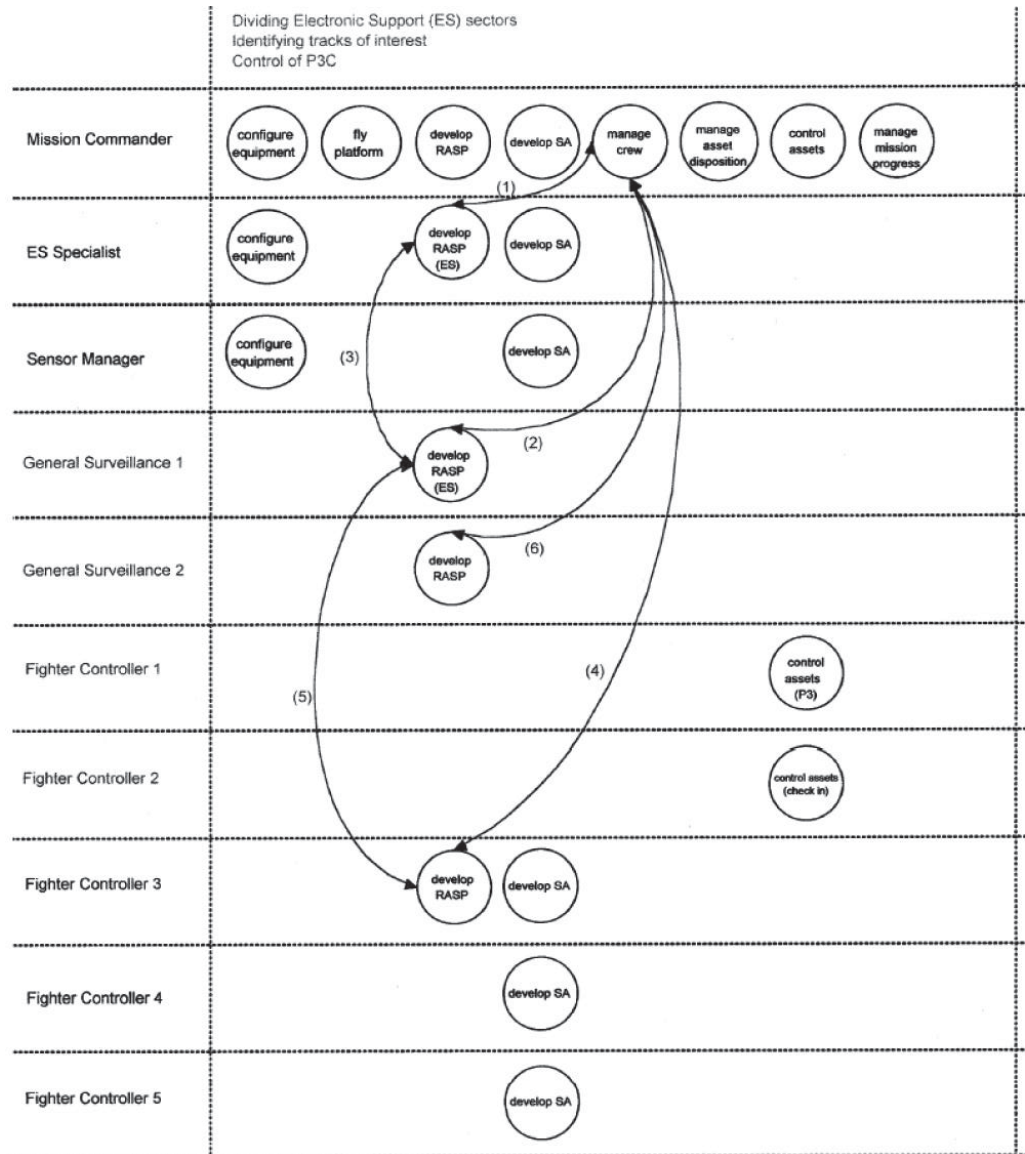
Extending CWA to support RE
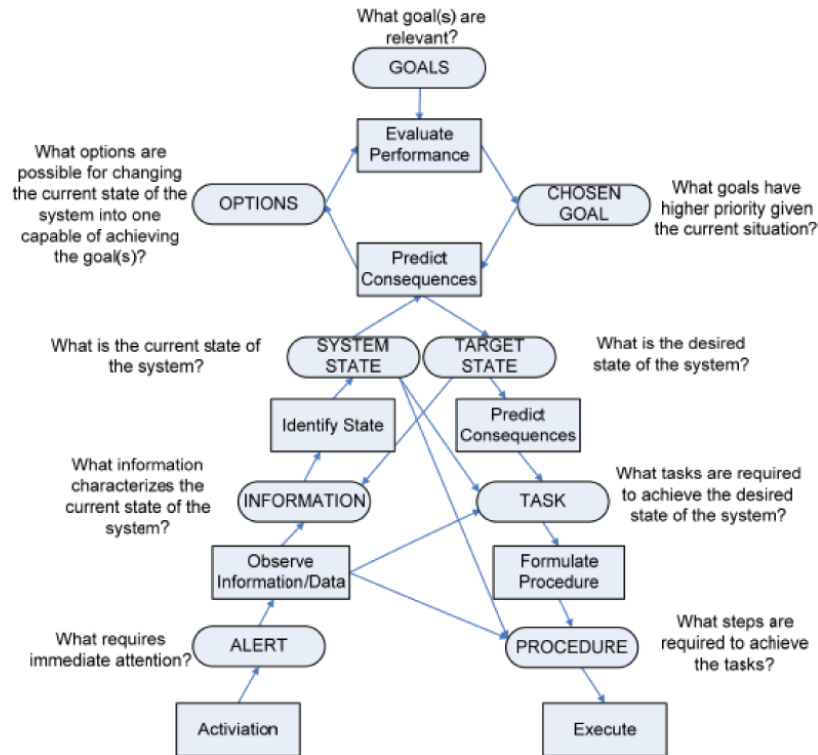
Extension and annotation by Elix & Naikar (2009)

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CWA has been successful so far

- DSTO Director general: 'All acquisition projects should use WDA'

- DSTO Deputy secretary: 'WDA should be introduced into acquisition cycle before options analysis'

- "System Program Office… judged that this team design was better than the designs they had independently considered for AEW&C in the past. As a result, the team design that we developed has been adopted … [corresponding technical alterations] were made prior to the contract's being signed … at no cost to the Commonwealth of Australia"

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Transition to CF acquisition processes

- Software RE evolving quickly, but our topics are still "future work" (Cheng & Atlee, 2007)
  - 'Ultra Large Scale systems'
  - Correspondence-driven, open systems
  - Requirements for context-conditioned variability
  - Interconnecting varied requirements models
- Yet most software requirements still developed with flexible, easy-workflow UML
- What CF workflow must a RE & OA process fit into to be adopted?

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Annex B   An overview of the CF procurement process

The following pages reproduce the slides summarizing the results of the review of the CF procurement process. These slides were presented at the project workshop held on 21-22 January 2010.

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Overview of the CF Procurement Process

Tasks 2/3 Workshop

21 January 2010

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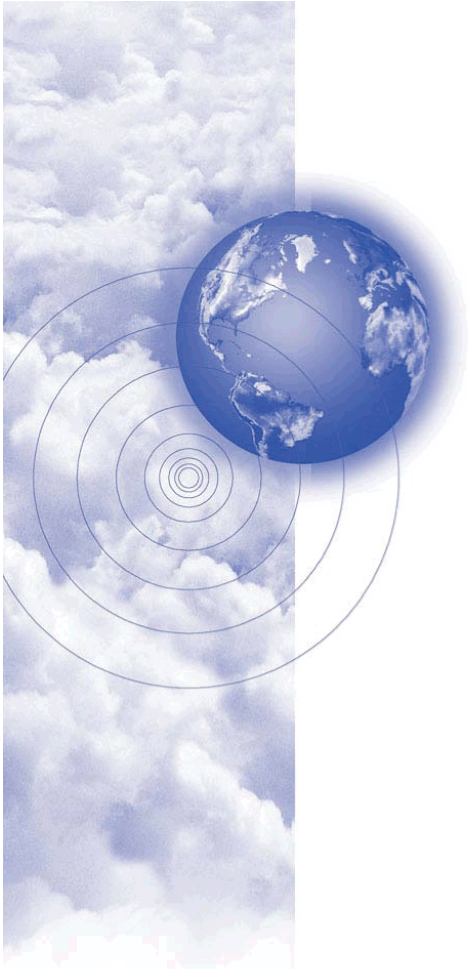
Objectives

- Provide an overview of the CF procurement process

- Discuss 'soft' factors at work at each phase

- Identify
  - Opportunities
  - Challenges

    …for the current project in this context

- Propose a process

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Overview of the CF Procurement Process

- Objective: to situate all procurement within the overall objectives of the Canadian Government
- On paper:
  - Ministerial direction
  - Long-term objectives of the CF
  - Strategic Capability Roadmap (to achieve above)
  - Development of Operational Requirements (to achieve above)
  - Development of Implementation Requirements (to achive above)
- Investment plans accompany each step

2

The Simplified Environment

Cap Dev Sponsor PMO Contractor/Subs

SCR
HLMC
IP

SOR
IP

SOW/
Spec

Esterline CMC Electronics
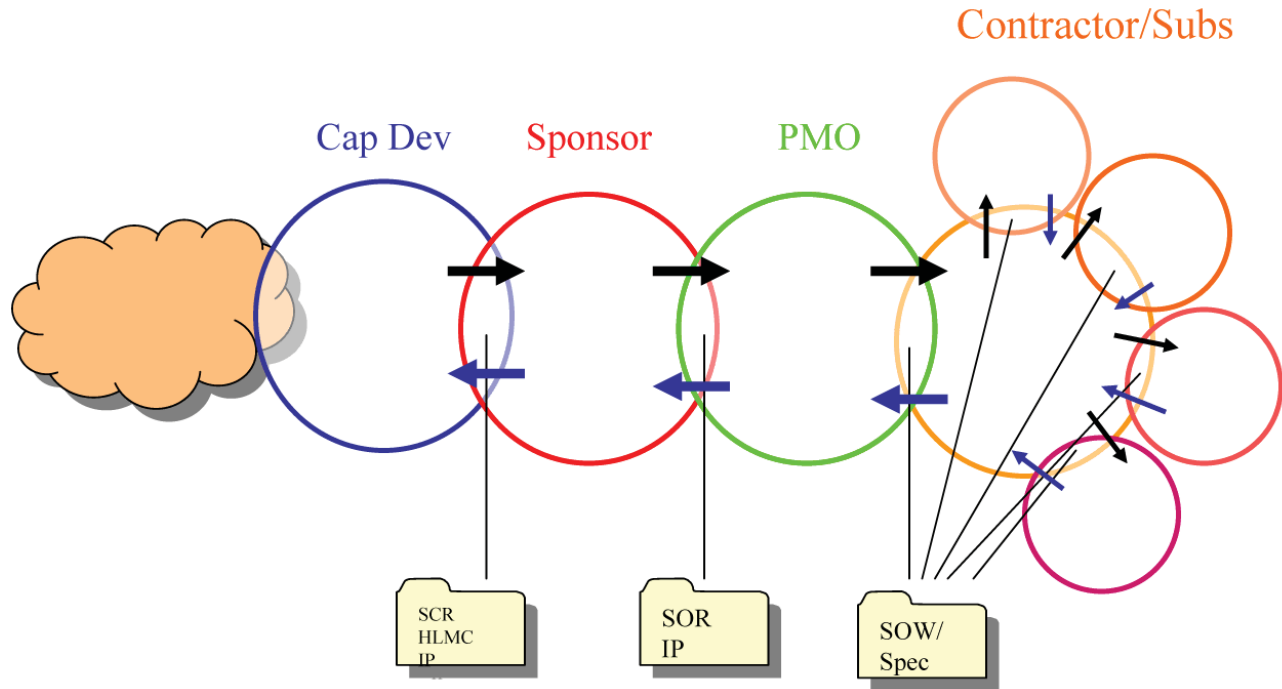
Phase 1: Capability-based planning

*"Capability-based planning is a **systematic approach** to force development that aims to advise on the **most appropriate force options to meet government priorities**. The process assesses **Government of Canada policy, CDS guidance, and capability goals derived through scenario analysis**. It identifies and validates capability deficiencies and affluences through the **analysis of current and programmed capabilities**. Capability-based planning supports the development of the preferred force structure that will be captured in the **strategic capability roadmap**, which will enable the provision of coherent advice to the **development of the Investment Plan**."*

Capability-based planning handbook, v. 5.2, 2008 (Draft)

4

Phase 1: Capability-based planning

- Players
  - Operational staff (as opposed to engineers)
  - Led by Chief of Force Development
  - High-level players, strategic effort

- Drivers
  - Government policy
  - Overall purpose of CF
    - Defence of Canada
    - Defence of North America (in co-op with US)
    - Contributions to safer, more secure security environment
  - Scenarios

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Phase 1: Capability-based planning

- Process
  - – Initiating directive (understand why planning is happening)
  - – Capability assessment for each domain (good and bad)
  - – Articulate capability deficiencies
  - – Assess mission value of capability deficiencies
  - – Develop capability alternatives
  - – Produce Strategic Capability Roadmap
  - – Articulate the domain roadmaps

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Phase 1: Capability-based planning

- Outputs
  - Future security analysis
  - Strategic Capability Roadmap
    - Prioritized list of capability deficiencies for next 20 years
    - Most important interface with next step
  - Project Identification (for $$$ purposes), called SS(ID)

- Opportunities
  - CWA may be a useful framework to capture assessment of future security situation

- Challenges
  - Human factors not yet in play; operational-level analysis
  - Evaluation of alternatives by military judgment

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Phase 2: Sponsor phase

- Objective
  - Deficiencies identified in SCR flowed down to sponsors
  - Developed from deficiencies to statements of operational requirements
  - Fleshes out SCR with high-level operational view
- Players
  - Operators, high-level staff from air, land, sea
- Drivers
  - SCR
  - Envisioned possibilities at time of implementation
- Process
  - Unclear
- Outputs
  - Statement of Operational Requirement (SOR); motivating doc for establishment of project
  - Preliminary project approval (for $$$ purposes); called SS(PPA)

Phase 2: Sponsor phase

- Opportunities
  - Options analysis is very active at this phase
  - DRDC/HFE can provide assistance to assess options, inform of human risks, opportunities

- Challenges
  - Alternatives are high-level, abstracted away from humans
  - Human factors may be viewed as an implementation detail
  - Limited budget to perform analyses

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Phase 3: Project phase

- Objective
  - Decompose SOR into a set of requirements that can be implemented (by 3rd parties)
  - Stay within fiscal boundaries

- Players
  - Engineers

- Drivers
  - SOR
  - Ongoing input from operators

- Outputs
  - Implementation requirements → SOW
  - Funding (called SS(EPA))

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Phase 3: Project phase

- Opportunities
  - Most concrete place to verbalize HFE requirements
  - Most detailed view of project
  - $$$ available for risk reduction; HFE techniques do this
- Challenges
  - How to specify design without favouring specific bidder?
  - Requirements for implementation audits increases bidder risk, hence increases bidder cost
  - Crown favours performance requirements
  - Vendors can choose not to comply with requirements (at their risk)
  - Once contract is won, vendors aim to only comply with requirements
  - Prime / subcontractor relationships
  - PMO wants control (will put no outside org on critical path)
  - PMO has limited funding, manpower

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Phase 3: Project Phase

- Levers
  - Mandate design
  - Mandate process
  - Mandate compliance to specifications (e.g., MIL-STD-1472F)
  - Mandate performance (but how to measure? Actually a process by another name)

Investment view
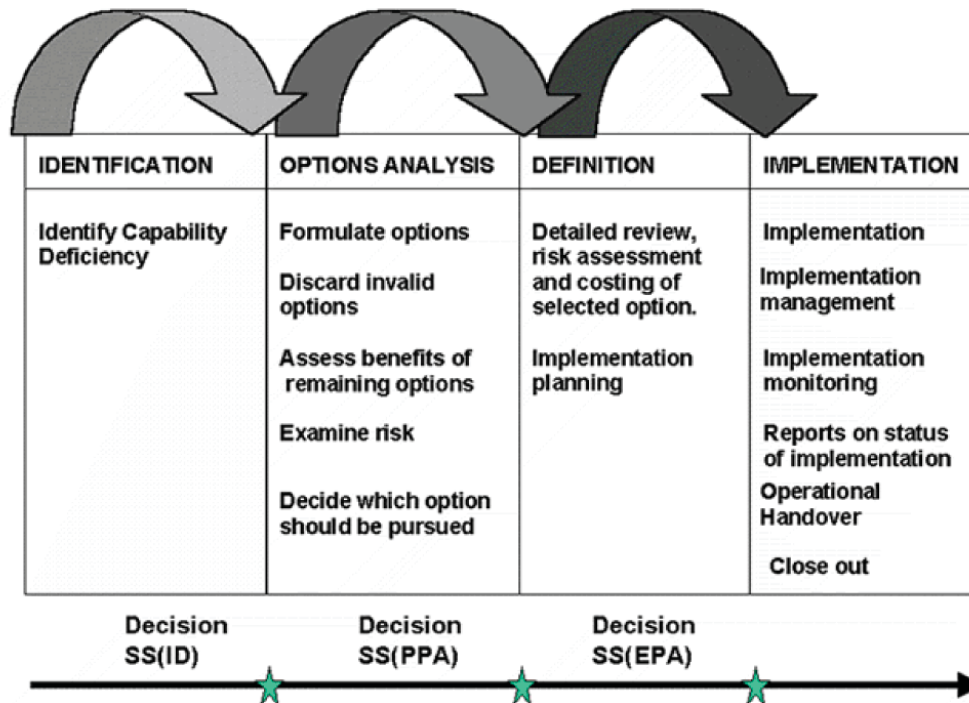
Questions at each level

- Phase 1: Capability-based planning
  - What types of platforms will address capability deficiencies?
- Phase 2: Sponsor phase
  - What are the operational characteristics of the platform required?
- Phase 3: Project phase
  - What are the technical characteristics of the platform required?
  - What are the evaluation criteria to assess if requirements met?
  - What is the procurement strategy to maximize chance of success / minimize cost?

- Reflection
  - Our work needs to be top-down (what are the questions that need to be addressed?), but informed by bottom-up (what are the types of questions we can answer?)

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Summary

- CF procurement is (on paper) a systematic decomposition
  - CF objectives → capability deficiencies → project identification → operational requirements → technical requirements → procurement
- CF procurement is (in practice) chaotic
  - Overall challenges of system development
  - Compounded by funding constraints
  - Compounded by posting cycle
- HFE/M&S potential
  - Assist in options analysis
  - Reduce operational risk
  - Develop organizational memory
- HFE/M&S challenges
  - Important assumptions required when design details not known
  - "Precision that rapidly outstrips accuracy"
  - Impact on procurement timelines, funding

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List of symbols/abbreviations/acronyms/initialisms

ADS. Abstraction-Decomposition Space
AFCS. Automatic Flight Control System
ARP. Applied Research Project, Applied Research Project
CBP. Capability Based Planning
CDRL. Contractor Data Requirements List
CF. Canadian Forces
CFD. Chief of Force Development
ConOps. Concept of Operations
ConTA. Control Tasks Analysis
COTS. Commercial-Off-The-Shelf
CWA. Cognitive Work Analysis
DID. Data Item Description
DND. Department of National Defence
DNDAF. DND/CF Architectural Framework
DRDC. Defence Research & Development Canada
HF. Human Factors
HLMC. High-Level Mandatory Capability, High-Level Mandatory Capability
HSI. Human Systems Integration
JUSTAS. Joint Unmanned Surveillance Target Acquisition System
M&S. Modelling & Simulation, Modelling & Simulation
MALE. Medium Altitude Long Endurance
MH. Maritime Helicopter

MHRS. MH Requirements Specification
MOC. Military Occupation Code
MODAF. Ministry of Defense Architectural Framework
NASA. National Aeronautics and Space Administration
PMO. Project Management Office
PRICIE. Personnel/Leadership/Individual Training, Research and Development/Operational Research, Infrastructure, Environment and Organization, Concepts, Doctrine, Collective Training, Information Management & Technology & Equipment Support
R&D. Research & Development
RFP. Request for Proposal
SCR. Strategic Capability Roadmap
SOCA. Social Organization and Cooperation Analysis
SOR. Statement of Operational Requirement
SOW. Statement of Work
SysML. Systems Modeling Language
UAV. Unmanned Aerial Vehicle
UML. Unified Modeling Language
WDA. Work-Domain Analysis

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13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

This report presents the results of a scoping study that was conducted to develop a Research & Development roadmap for Project 14dj, *Modelling and Simulation for Requirements Engineering and Options Analysis.* The purpose of Project 14dj is to develop a Modelling & Simulation capability, comprised of analytical techniques and software tools, for addressing human factors issues commonly encountered by Canadian Forces acquisition projects. This scoping study developed a roadmap for this research by developing insights and research questions from the current Canadian Forces procurement process, the academic and applied literature on requirements engineering and options analysis, and through expert advice on how Cognitive Work Analysis could be applied to CF procurement. 24 research questions are developed, which are structured into five specific research proposals for Defence R&D Canada to consider for inclusion in Project 14dj.

Ce rapport présente les résultats d'une étude de délimitation de projet visant à élaborer un guide de Recherche et Développement pour le Projet 14dj, Modélisation et simulation pour l'ingénierie des besoins et l'analyse des options. Ce projet a pour but de développer une capacité de Modélisation et simulation composée de techniques d'analyse et d'outils logiciels, pour résoudre des questions liées aux facteurs humains qui se posent souvent dans les processus d'acquisition des Forces canadiennes. La présente étude de délimitation de projet a permis d'élaborer un guide pour cette recherche en développant des perspectives et des questions de recherche à partir du processus d'acquisition actuel des Forces canadiennes, de la littérature didactique et des études appliquées à l'ingénierie des besoins et l'analyse des options, et par des conseils éclairés sur la manière dont l'Analyse du travail cognitif peut être appliquée aux acquisitions des FC. Vingt-quatre questions de recherche sont développées et reparties en cinq projets de recherche que R&D pour la défense Canada pourra examiner et inclure dans le Projet 14dj.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

modelling; simulation; requirements; engineering; options; analysis; cognitive; work