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Aligning modelling and simulation capabilities to support the Royal Canadian Navy's platform acquisition projects

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Abstract

This report summarizes a series of surveys to understand the Human Systems Integration (HSI) challenges encountered in major Canadian Forces (CF) capital acquisition projects and the role of Modelling and Simulation (M&S) as a potential solution. The study targeted three on-going naval platform acquisition effort, including the Joint Support Ship project (JSS), the Arctic/Offshore Patrol Ship project (AOPS), and the Canadian Surface Combatant project (CSC). Subject Matter Experts (SME) from these three projects as well as other key stakeholders in the acquisition process were interviewed. The study reviewed the standard Department of National Defence (DND) procurement process, examined the HSI challenges in each phase of the process and their implications on M&S capability requirement. The results identified a list of key challenges prioritized in the context of JSS, AOPS and CSC, and, correspondingly, the M&S capabilities required to address these challenges. In particular, the development of a human centric architecture framework and its application in the JSS were rated as top priority. The findings assisted the finalization of research objectives for a Defence Research and Development Canada (DRDC) Applied Research Project (ARP) 14dj.

Résumé

Le présent rapport résume une série d'études visant à améliorer la compréhension des défis en matière d'intégration des systèmes humains (ISH) que posent les principaux projets d'acquisition d'immobilisations des Forces canadiennes (FC), ainsi que du rôle de la modélisation et de la simulation (M & S) comme solution potentielle. Ces études visaient trois projets d'acquisition de plates-formes navales en cours, notamment les projets d'acquisition de navires de soutien interarmées (NSI), de navires de patrouilles extracôtiers de l'Arctique (NPEA) et de navires de combat de surface canadiens (NCSC). On a interrogé des experts en la matière (EM) de ces trois projets ainsi que d'autres participants clés au processus d'acquisition. Dans le cadre de ces études, on a passé en revue le processus d'approvisionnement standard du ministère de la Défense nationale (MDN) et examiné les défis en matière d'ISH de chaque phase du processus, ainsi que leurs répercussions sur l'exigence relative à la capacité M & S. Les résultats obtenus ont permis de dresser une liste des défis clés priorisés dans le contexte des NSI, des NPEA ainsi que des NCSC et, par conséquent, des capacités M & S requises pour relever ces défis. En particulier, l'élaboration d'un cadre d'architecture centré sur la personne et son application en ISH ont été cotées « priorité absolue ». Les conclusions ont aidé à l'atteinte des objectifs de recherche d'un Projet de recherches appliquées (PRA) de Recherche et développement pour la Défense Canada (RDDC), vecteur 14dj.

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Executive summary

Aligning modelling and simulation capabilities to support the Royal Canadian Navy's platform acquisition projects:

Wenbi Wang; DRDC Toronto TR 2011 - 172; Defence R&D Canada – Toronto; November 2011.

Introduction or background: Four on-going fleet modernization and replacement projects will define the shape of the Royal Canadian Navy (RCN) for decades to come. It is important for Human Factors practitioners to engage the operational community and become closely involved in the early stage of these projects.

The Human Modelling Group (HMG) has been leading an Applied Research Project (ARP), funded under 14dj, to develop manpower and personnel modelling capabilities to support the Navy's platform acquisition effort. A series of surveys were recently conducted in which eighteen Subject Matter Experts (SMEs) in the Navy's acquisition process were consulted on issues related to Human Systems Integration (HSI), particularly the common HSI challenges encountered by the project management office (PMO) and the role of Modelling and Simulation (M&S) as a potential solution.

The study identified both general and HSI-specific challenges in different phases of capital acquisition, and prioritized these challenges in the context of three on-going naval platform acquisition projects, i.e., the Joint Support Ship project (JSS), the Arctic/Offshore Patrol Ship project (AOPS), and the Canadian Surface Combatant project (CSC).

Results: The findings single out specific areas such as complement validation as key activities for which the demand for M&S support is anticipated. As a general direction for capability development, the following list describes the preferred M&S capabilities required to support these navy projects.

- A repertoire of Human Factors (HF) and HSI requirements;
- Modelling tools supporting the management of acquisition data throughout the entire acquisition project life cycle;
- Design software to support work space analysis and validation; and
- Capabilities in operational scenario generation.

Significance: Results assisted the 14dj ARP to formulate a capability development plan. It was decided that the project would focus on the development and application of human centric architecture framework, i.e., the Human Views (HV), in the context of the JSS project.

Future plans: Future application of the HV is expected for the CSC project.

Sommaire

Aligning modelling and simulation capabilities to support the Royal Canadian Navy’s platform acquisition projects:

Wenbi Wang; DRDC Toronto TR 2011 - 172; R & D pour la défense Canada – Toronto; Novembre 2011.

Introduction ou contexte : Quatre projets de modernisation et de remplacement de la flotte en cours établiront la forme de la Marine royale canadienne (MRC) pour les décennies à venir. Il importe que des spécialistes en facteurs humains fassent participer le milieu opérationnel et participent eux-mêmes étroitement à la première étape de ces projets.

Le Groupe de modélisation de l'humain (GMH) dirige un Projet de recherches appliquées (PRA), financé à partir du vecteur 14dj, visant à développer les capacités de modélisation en matière d’effectif et de personnel afin de soutenir le projet d’acquisition de plates-formes de la Marine. On a récemment mené une série d’études dans le cadre desquelles on a consulté dix-huit experts en la matière (EM) sur le processus d’acquisition de la Marine concernant des questions liées à l’intégration des systèmes humains (ISH), en particulier les défis courants en matière d’ISH auxquels est confronté le bureau de projet (BP) ainsi que le rôle de la modélisation et de la simulation (M & S) comme solution potentielle.

Ces études ont permis l’identification de défis de nature générale et spécifiques à l’ISH dans différentes phases de l’acquisition d’immobilisations, et priorisé ces défis dans le contexte de trois projets d’acquisition de plates-formes navales en cours, c.-à-d., les projets d’acquisition de navires de soutien interarmées (NSI), de navires de patrouilles extracôtiers de l’Arctique (NPEA) et de navires de combat de surface canadiens (NCSC).

Résultats : Les conclusions soulignent les domaines spécifiques, par exemple la validation de complément, en tant qu’activités clés pour lesquelles on s’attend à une demande en soutien de la M & S. Comme orientation générale en matière de développement des capacités, la liste suivante décrit les capacités en M &t S privilégiées que requiert le soutien de ces projets de la Marine.

- Un répertoire des exigences en matière de facteurs humains (FH) et d’ISH.
- Des outils de modélisation soutenant la gestion des données d’acquisition pendant toute la durée du cycle de vie du projet d’acquisition.
- Un logiciel de conception pour le soutien de l’analyse et de la validation de l’espace de travail.
- Des capacités de production de scénarios opérationnels.

Portée : Les résultats obtenus ont aidé le PRA financé à partir du vecteur 14dj à formuler un plan de développement des capacités. On a décidé que le projet serait axé sur le développement et l’application d’un cadre d’architecture centré sur la personne, c.-à-d., sur les vues humaines (VH), dans le contexte du projet des NSI.

Perspectives : On s’attend à l’application future des VH dans le contexte du projet des NCSC.

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Acknowledgements

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1 Introduction

The Royal Canadian Navy (RCN) has currently been undertaking one of its most extensive fleet modernization and replacement programs in its history. Three on-going acquisition projects, those being the Joint Support Ship project (JSS), the Arctic/Offshore Patrol Ship project (AOPS), and the Canadian Surface Combatant project (CSC), together with the Halifax Class Modernization/Frigate Life Extension (HCM/FELEX) project will define the shape of the RCN for decades to come. As these projects unfold, it is important for Defence Research and Development Canada (DRDC) to engage the operational community and become closely involved in these platform modernization and acquisition efforts. This is especially critical for Human Factors (HF) practitioners, for whom early involvement in system design, therefore early injection of user requirements in the design, has long been regarded as one of the key principles to ensure successful Human Systems Integration (HSI).

The Human Modelling Group (HMG) has been leading an Applied Research Project (ARP), funded under 14dj, to develop manpower and personnel modelling capabilities to support the RCN's acquisition projects. A series of surveys was recently conducted in which key stakeholders in the RCN's acquisition process were consulted on issues related to HSI, particularly the common HSI challenges encountered in the Project Management Office (PMO) and the role of Modelling and Simulation (M&S) as a potential solution. While specific findings related to manpower and personnel modelling were reported elsewhere [1], this technical report discusses a wider range of HSI issues identified in the survey and the prioritization of these issues from each PMO's perspective. Such information will assist the 14dj project, and the HMG in general, in future planning for M&S capability development. Although the PMO HCM/FELEX was not explicitly consulted in this study, many findings presented in this report can be applied in the frigate modernization process too.

Following the introduction, Section **2** provides a brief overview of on-going naval platform replacement and modernization projects. The setup of the SME survey is explained in Section **3**. General results are presented in Section **4**, with key findings further discussed in Section **5**. A brief summary of the study is presented in Section **6**.

2 Fleet modernization and replacement projects

The on-going fleet modernization and replacement projects reflect the RCN's vision to develop a combat capable multi-purpose fleet that is capable of supporting land operations, providing a sea-based national or international command capability, deploying tactical unmanned aerial vehicles and sustaining naval task group operations worldwide [2]. This Section provides a brief overview of three fleet replacement projects, namely JSS, AOPS, and CSC. HCM/FELEX is also included although the project was not explicitly consulted in the survey.

2.1. Joint Support Ship (JSS)

JSS will replace the RCN's current Auxiliary Oiler Replenishment ships, i.e., the Protecteur Class vessels, that are nearing the end of their service lives. The primary role of JSS is to replenish naval task groups and support shore-based Canadian Forces (CF) units by delivering supplies such as fuel, spare parts, food and water during international operations. The planned new ships will also be capable of serving as joint task force headquarters and supporting the evacuation of a limited numbers of people. In addition, each ship is also planned to support up to three maritime helicopters.

Two ships will be procured by JSS, with an option to acquire a third. The first ship is planned to be delivered in 2017, followed by the second in 2018.

2.2. Arctic/Offshore Patrol Ship (AOPS)

AOPS has been established to deliver a naval ice-capable offshore patrol ship to assert and enforce sovereignty in Canada's waters. These ships will provide the flexibility for the RCN to operate in both the Arctic and other offshore environments, allowing them to be used year-around in a variety of roles, including domestic surveillance, search and rescue, and support to other government departments. Highlights of the proposed ship capabilities include:

- Operating in Canada's waters, including the Arctic, and from time to time, operating in waters contiguous to continental North America;
- Navigating in medium (1 metre) first-year ice, which may include old ice inclusions;
- Sustaining operations for up to 120 days and a range of at least 6800 nautical miles;
- Supporting boat operations such as shore landings and naval boarding parties, and supporting the operations of one helicopter; and
- Embarking and operating a light helicopter with provision for providing limited supporting for the CH 148 Cyclone helicopter.

The project is currently planned to deliver six to eight ships from 2015 to 2021.

2.3. Canadian Surface Combatant (CSC)

CSC will procure up to fifteen new ships in a twenty-year plan to replace the Iroquois Class destroyers and the Halifax Class frigates when they reach the end of their operational lifecycle. It will be one of the largest capital equipment acquisition projects in the Canadian government's history, representing approximately half the amount of the estimated acquisition cost for all projects identified in the Canada First Defence Strategy [3]. The current plan is to build the first three or four lead ships that will provide key capabilities currently residing in the destroyers such as area air defence, control at sea, and task group command and control. The follow-on ships will be more like frigates.

The design plan is to adopt a common hull form for all CSC ships, utilize a common engineering plant and core equipment, and rely on a modular (e.g., plug-and-play) engineering concept wherever feasible. The destroyer and frigate variants will be fitted with different weapons, communications, and surveillance systems as required. The goal of such a design plan is to ensure that CSC can be deployed in either a general-purpose or a mission-tailored configuration, thereby enhancing the RCN's operational flexibility. The delivery is currently planned to start in 2021.

2.4 Halifax Class Modernization/Frigate Life Extension (HCM/FELEX)

HCM/FELEX is responsible for the mid-life refit of the Halifax Class frigates. The RCN's existing twelve frigates were launched in the early 1990s and were originally designed to be operational for thirty years. The main goal of the mid-life refit is to upgrade the ships, particularly the combat systems, and expand the frigates' operational profile to handle faster and stealthier threats that increasingly occur in the littoral environment. As currently planned, the last frigate will complete its refit in July 2016 and all ships are scheduled to be operational by January 2018.

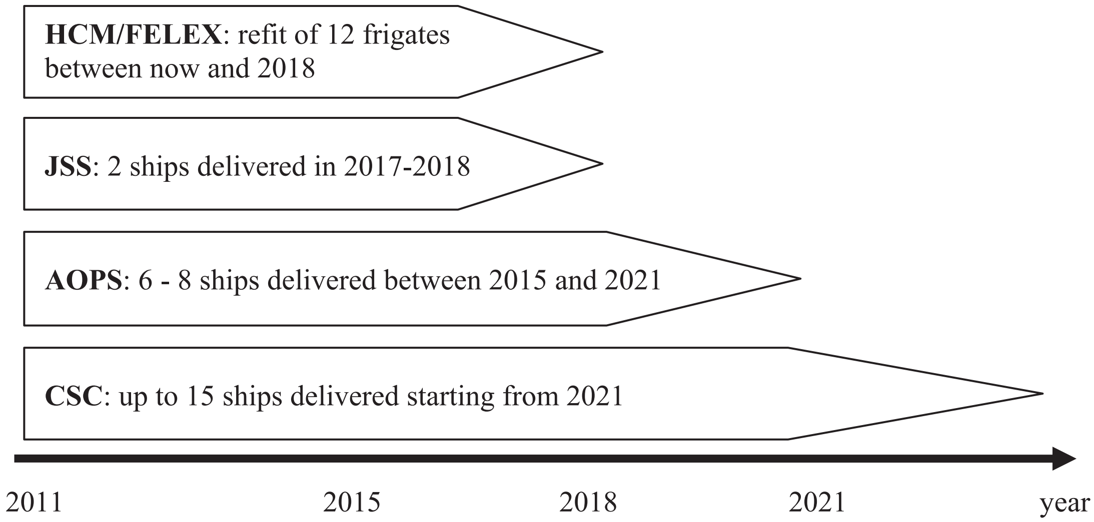

Figure 1:An illustration of the platform delivery and project completion time for four on-going fleet modernization and replacement projects.

Figure 1 shows a timeline of these projects based on either platform delivery or project completion time. In the cases of JSS, AOPS and CSC, the acquisition processes have already been started and the PMOs have been established. Given the different vessel types and project timelines, there exist significant differences in the procurement strategies adopted across these projects. It is important for the Science and Technology (S&T) community to understand these procurement strategies and develop Research and Development (R&D) plans accordingly. For example, a procurement strategy that focuses on procuring Military-Off-The-Shelf (MOTS) systems requires a different set of S&T support tools and processes compared with an alternative strategy emphasizing indigenous designs. The current survey study was conducted to understand the RCN's requirements and their priorities from individual project perspectives.

3 Stakeholder surveys

The study consisted of five surveys in which Subject Matter Experts (SMEs) involved in Department of National Defence (DND) acquisition were interviewed. The following list explains the main objectives of the survey:

- To understand the acquisition process and the HSI challenges encountered in different phases of system procurement;
- To identify HSI challenges that may be resolved by using M&S;
- To understand the project-specific challenges faced by JSS, AOPS and CSC, and the prioritization of these challenges; and
- To develop an R&D roadmap that guides M&S capabilities development for the 14dj ARP.

A total of eighteen SMEs were interviewed. They came from a variety of DND organizations, representing different stakeholders in the capital acquisition process. Specifically, the study focused on the PMOs of three RCN acquisition projects and invited key personnel, e.g., the project director, the project manager, the requirements engineer, and the HF engineer, into the survey wherever possible. The SMEs were not paid for their participation because the interview and the questions probed by the survey were considered within the scope of their normal duties.

The surveys took place between July and August 2011. The duration of each survey lasted from 1.5 to 2 hours. In each session, a questionnaire was used and a semi-structured interview format was followed. The questionnaire consisted of three main categories of questions which were designed to probe issues related the acquisition process, HSI challenges, and M&S application. A full copy of the questionnaire is available in [1]. Although the questionnaire was created with an emphasis on manpower and personnel modelling, i.e., the target domain of the 14dj ARP, the SMEs were encouraged to raise any HSI issues encountered in their respective work domains.

SME responses were recorded by a team of analysts. They were then collated and a summary of key findings is presented in the following section.

4 Results

The survey results were grouped into three topic areas. Sub-Section **4.1** describes the procurement process followed by DND acquisition projects, in particular the tasks and deliverables required for each phase of acquisition. Such information assists the project team of 14dj to identify acquisition phases where the injection of M&S support is most beneficial. The survey also revealed the procurement strategy and a more detailed project timeline for JSS, AOPS and CSC, a brief summary of which is provided to support future DRDC project planning. Sub-Section **4.2** discusses the high-level challenges encountered in each phase of acquisition. Many of them reflect theoretical and practical constraints that could arise in any acquisition effort. The list of concerns included in this report is not exhaustive; however, concerns are selected based on subjective judgment whether or not a link to an M&S solution can be established. Sub-Section **4.3** summarizes the HSI challenges discovered in this study. Given the background of SMEs, the findings inevitably reflect an emphasis on navy platform acquisition. However, many findings are applicable to other domains of CF acquisition too.

4.1. DND acquisition process

DND acquisition projects are required to follow a standard project management process, which consists of five phases as depicted in *Figure 2*. The overview below intends to capture the key activities in the process and provides the necessary context in which later discussion on acquisition challenges can be held.

The initiation of an acquisition project starts with identifying a deficiency in the CF's capability. At the highest level, ministerial direction and CF long-term objectives (e.g., [3]) provide the policy context in which acquisition decisions can be made. In response to the policy context, Capability-Based Planning (CBP) is initiated to develop a prioritized list of capabilities for procurement over the planning horizon. When a project identified in the CBP is given preliminary funding, the project is allocated to one of the environments (i.e., Army, Navy, or Air Force) and a group of operators are assigned to a PMO which then takes on the responsibilities to acquire the system. As an acquisition project unfolds, it goes through five phases. The main tasks in this process involve the formulation and analysis of system options, conduction of risk assessment, planning and monitoring system implementation, and the eventual system handover.

IDENTIFICATION	OPTIONS ANALYSIS	DEFINITION	IMPLEMENTATION	CLOSEOUT
Identify capability deficiency	Formulate options Discard invalid options Assess costs and benefits of remaining options Examine risk Decide which option should be pursued	Detailed review, risk assessment and costing of selected option. Implementation planning	Implementation Implementation management Implementation monitoring Reports on status of implementation Operational Handover	Capture lessons learned Close out activities

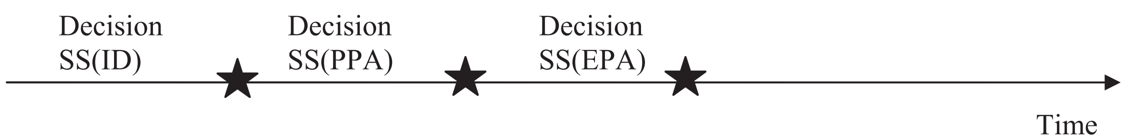

Figure 2: The five management phases in DND acquisition process. Note, SS(ID), SS(PPA) and SS(EPA) refers to Synopsis Sheet (Identification), Synopsis Sheet (Preliminary Project Approval) and Synopsis Sheet (Effective Project Approval), respectively.

The outputs from these activities are captured in a series of project documents, including various Synopsis Sheets (SSs) used in different stages of project approval, the Project Charter, the Statement of Operational Requirement (SOR), and the Project Profile and Risk Analysis (PPRA) report. Not only are these documents project records of the acquisition process, they also serve as the medium for communicating to different stakeholders. Since a significant portion of work in a PMO is related to the generation of these documents, it is a key area that the 14dj ARP decided to examine closely in order to identify processes and tasks where S&T support will create the greatest client impact. A complete list of these documents, corresponding to the project phases, is depicted in *Figure 3*.

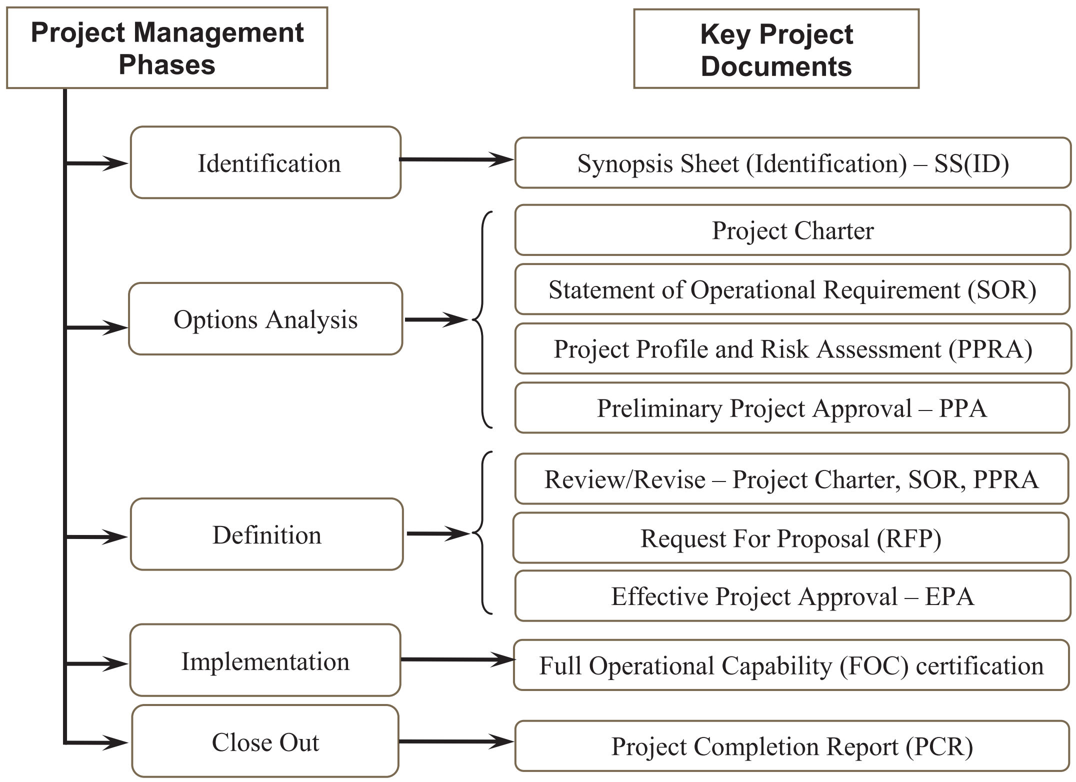

Figure 3: Key project documents produced at different phases of an acquisition project.

Given the complexity of capital acquisition, these projects are typically supported by a team of experts with a wide range of backgrounds. For engineering issues, most projects are organized with a similar structure. A team of CF operators, led by the Project Director (PD), is responsible for the creation of system requirements. With domain expertise about military operation, the PD ensures the acquired system will satisfy the needs of the CF. The system requirements are then translated into technical specifications by a team of mostly engineers, headed by the Project Manager (PM). Such specifications are eventually included in an RFP and are sent to the potential vendors for contract bidding. While the PD's and PM's team together forms a PMO, it is useful to note the different chain of command for these two teams. Specifically, the PD typically reports to the requirement organization of one of the CF environments, i.e., Director of Land Requirements (DLR), Director of Maritime Requirements (DMR), and Director of Air Requirements (DAR), whereas the PM reports to the Assistant Deputy Minister (Materiel) (ADM(Mat)). After the acquisition contract is awarded, the system requirements are passed to the vendor who is responsible for the design and implementation of the system according to the technical specifications. Although such a configuration creates checks and balances for necessary quality control in the acquisition process, it also imposes some challenges which will be elaborated in Sub-Section **4.2**.

With respect to three naval acquisition projects, the surveys revealed that JSS is currently in its options analysis phase. A two-pronged procurement approach has been pursued in which an "in-house" design will compete against two existing ship designs. With the planned SS(EPA) approval in Summer 2013 and the shipbuilding contract award in Fall 2013, the project expects the delivery of the first ship in Spring 2017. As of now, JSS is planned to be closed out by Fall 2019.

For AOPS, the project is currently near the end of its definition phase. With the finalization of the government's decision on shipyard selection (i.e., the National Shipbuilding Procurement Strategy), the project will quickly move into the implementation stage. The current plan is to set up the implementation contract in 2012 and start the delivery of the first AOPS ship in 2015.

For CSC, the project is currently in the early options analysis phase. At the time when the survey was conducted, the PMO CSC had recently gone through significant personnel changes due to the CF posting cycle. Since CSC intends to focus on a new ship design, it is expected that a wider range of HSI issues will need to be examined. Additionally, given that the surface combatant will become the backbone of the future RCN, it is generally regarded as the most important naval acquisition project against which S&T resources should be dedicated.

4.2 Common challenges in capital acquisition

While the process depicted in Figure 2 reflects the CF's vision on how to manage capital acquisition projects, in reality, every project follows the process in different ways driven by a variety of constraints. For example, the current study revealed that many CF procurement projects are chronically under-staffed and under-resourced; the issue is often further exacerbated by the posting cycles of personnel in the PMO. However, since such issues are beyond the scope of the 14dj ARP, they are not emphasized in this report. The following discussion focuses on challenges that potentially can be addressed by injecting S&T support. Common difficulties in each phase of acquisition are described in this subsection, while specific HSI challenges are covered in Sub-Section **4.3**.

4.2.1 Challenges in requirement generation

Successful acquisition depends on procurement of the right equipment. An important criterion for judging what is right depends on whether or not the equipment is sufficient to assist the CF in achieving its operational objectives. Therefore, it is critical in any acquisition project to provide a comprehensive description of the operational requirements envisioned for the system in the early stage of acquisition.

This is a difficult task with many levels of challenge, two of which are highlighted here. The first challenge is the task - artefact cycle effect which describes a dilemma in the system design and acquisition process: the design and development of a new system depends on the projection of its operational requirements; these requirements are difficult to obtain a priori and are often biased by the existing ways to achieve missions with similar legacy equipment. As a result, many new systems, designed based on existing operational and technical conditions which are altered after the deployment of the new systems, may fail to achieve their original design goals [4].

The second challenge is the difficulty in capturing the CF operator's tacit knowledge in the SOR. Examples of such knowledge include domain expertise about CF operations that is shared by the requirement developers but not always explicitly expressed in the SOR. The lack of such information leads to issues such as undocumented assumptions, which can create problems later when the requirements are passed to engineers (e.g., from either the PM staff or the vendor) who possess less domain knowledge.

4.2.2 Challenges in translating system requirements into technical specifications

While the generation of operational requirements faces many roadblocks, the follow-up step to translate these requirements into technical specifications is no less challenging. Given the complexity of modern military systems and the existence of a wide range of technological options, it is difficult to produce an appropriate level of technical specifications that ensure the system's operational capabilities match the CF's objectives and, at the same time, leave sufficient flexibility to the vendor so that engineering ingenuity is not limited. This is further complicated by the need to make specifications achievable and affordable by MOTS technologies. This challenge sometimes leads to an often undesirable acquisition practice of targeting a particular system solution. For large air and maritime platforms, due to the often limited MOTS options, the approach becomes quite attractive, fixating on a particular platform and conducting "reverse engineering" by matching the target platform's specifications to the project's operational requirements. While such a platform-based acquisition strategy sometimes may bring in short-term cost savings, its limitations should not be overlooked.

Another common approach to create a system's technical specifications is by studying the specifications for a legacy system and modifying them based on the differences (e.g., functional and operational differences) between the new and existing systems. This approach is often referred to as the *bottom-up* method, in contrast to an alternative *top-down* method in which the technical specifications are developed based on an iterative analysis of the system's mission objectives, functional components, task activities, and eventually equipment technical requirements. Both approaches have pros and cons, and their suitability is likely determined by specific acquisition project requirements. The need for M&S inputs, however, differs between these two methods. For example, conceptual models of a system are likely treated as more important for a top-down analysis given the lack of a legacy platform as a baseline reference for describing the system.

4.2.3 Challenges in system implementation

There could be numerous difficulties in complex system design and development. The one highlighted here is the gulf between the problem and solution spaces, a conceptual challenge often discussed by system engineering professionals [5]. If one considers the creation of system requirements and technical specifications as tasks in the problem space, then the activities performed on the vendor side, i.e., system design, can be regarded as tasks in the solution space. Differences between the PMO and vendor, such as different mental models of the envisioned operational environments, are exemplar factors that lead to gaps between the problem and solution spaces. The lack of tacit knowledge in the SOR, as discussed previously, can lead to design problems in the implementation phase. The fact that large capital acquisition often involves a consortium of sub-vendors increases the likelihood of running into such problems.

4.3 HSI challenges

Besides the general challenges described above, the SMEs also raised a list of obstacles related to HSI in their respective world of work. Overall, the generation of human requirements and their translation into technical specifications are considered difficult tasks. The specific challenges pointed out by the SMEs are categorized below according to the five HSI domains adopted by DND [6].

1. *Manpower*. Manpower is a major issue faced by all three PMOs. As a subdomain of HSI, manpower is concerned with the number of military and civilian personnel required and potentially available to operate, maintain, sustain, and provide training for a military system [7]. Given that personnel cost is a major component in the overall life-cycle cost of a naval platform, there exists significant pressure to reduce the size of a ship's crew. The theme on austere manning has been investigated by allied navies for more than a decade [8 - 9]. The current study found out that specific crew size had been provided as a design objective for three projects. For example, JSS sets a goal to reduce the crew size by at least 30% compared to its predecessor vessels, and the target of its standard crew is up to 165 sailors per ship, excluding the air crew. The crew size goal for AOPS is between 35 and 45 sailors. As of now, no specific crew target has been announced for CSC, but the project has invested in research to identified methods and modelling tools that can support its crewing optimization effort [10].

Detailed initial crewing plans have been completed for JSS and AOPS. At least in the case of JSS, the complement solution was produced by an industrial partner. According to the SMEs from PMO JSS and PMO AOPS, these plans were created following a bottom-up approach, optimizing the existing manning solution used by the predecessor ships. Manning reduction is achieved by replacing manual human tasks with automation. For JSS and AOPS, the SMEs suggested that the burning issues in crewing analysis is less about the generation of a complement solution, which could be created by tweaking existing platform solutions to achieve the imposed crewing target. The difficulty however is complement validation, that is, the verification and validation on whether or not a particular complement solution will meet the Navy's mission objectives under a variety of operational scenarios. Right now, none of the three PMOs has access to tools for supporting this task.

Different from JSS and AOPS, complement generation is considered a high priority for CSC. Since the surface combatant introduces many new design concepts and will replace two types of legacy vessels, the conventional bottom-up approach becomes less ideal. The alternative top-down approach, at least in principle, should enable the Navy to examine novel manning concepts that are hard to develop by purely studying existing ways the destroyers and frigates are manned now. To support such an approach, modelling tools need to be developed to facilitate both manpower needs analysis and complement design.

2. *Personnel*. Another important aspect of complement generation is the design of rank structure, that is, specification of the rank level for each crew member. Fundamentally, the design should examine the planned tasks for each member, analyze the cognitive and physical characteristics imposed by these tasks, and then match the requirements to the CF occupational systems, in particular, linking the requirements to the type and level of Knowledge/Skills/Abilities (K/S/A) defined in the CF rank system. Although the naval conventions should be respected, in areas where new functions are performed (e.g., as a result of automation use), systematic methods for

selecting the proper rank level is required. This issue was highlighted by the SMEs from PMO CSC.

3. *Training*. The importance of training was recognized in all three projects. Particularly in CSC, due to the large manning pool required to man the entire fleet of CSC ships, the project has recognized the complexity in future training needs analysis. However, the issue was not rated as urgent by any of the PMOs. On the other hand, other organizations such as Directorate of Maritime Personnel (D Mar Pers) showed a greater interest in developing analytical methodologies and modelling tools to support structured training analysis.

4. *System Safety and Health Hazards*. In this domain, the issue of concern appears to center on damage control. Projects such as CSC recognized the importance of damage control in determining the manpower demand. As shown by previous studies, operational scenarios based on damage control can be used as an effective way for validating crewing plans under stressful scenarios [10 - 12].

5. *Human Factors Engineering*. The request for Human Factors Engineering (HFE) support differs across the projects. For example, CSC anticipates a greater demand for HF expertise and has included an HF engineer in its team, whereas the other two projects plan to obtain HF advice from external organizations. Among the issues raised in the survey, a common HFE concern converges on spatial layout analysis of key compartments like the ship's bridge. This is a capability required by the HCM/FELEX project as well, before the installation of new sensors and weapon systems takes place in a frigate's refit process. Additionally, CSC also expressed an interest in anthropometric modelling and its application in physical ergonomic system design. Demand for such capabilities is expected as the project further unfolds.

Notably, many important HFE topic areas, such as Operator Machine Interface (OMI) design and mental workload assessment, were not rated as burning issues by these PMOs. This however by no means indicates that these areas are not important. On the contrary, many SMEs admitted issues such as operator workload analysis are very important, however, such types of analysis are considered appropriate for a later stage of procurement such as in the design and implementation phase. Some suggested that the responsibility for performing these analyses should belong to the vendor. Many expected that external organizations like DRDC would be called upon to evaluate vendor's assessments when the need arises in an independent verification and validation role.

5 Discussion

It is generally agreed that M&S can play an important role in the acquisition process, particularly the use of models at the early conceptual design stage to generate assumptions and support preliminary options analysis when design details are not known. The term simulation-based acquisition reflects this particular school of thought to promote the extensive application of computational M&S techniques in supporting acquisition decisions. The current study, however, revealed many difficulties that prevent the achievement of this goal.

The section starts with a summary of the current state of M&S use in the PMOs, followed by a discussion on the type of M&S capabilities required to support three RCN projects. Two additional insights, i.e., M&S capability to assess automation use and a System-of-Systems (SoS) approach toward M&S, are captured in the final sub-section.

5.1 Current use of M&S in JSS, AOPS and CSC

The survey revealed that M&S had played a minimal role in three PMOs up until their current stage of development. The PMOs do not have access to M&S tools, although PMO CSC plans to examine the feasibility of a number of modelling platforms for the project's needs. The general sentiment among the SMEs is that the idea of using M&S is good, but a number of limitations prevent its adoption in PMO's workflow.

The first major limitation is the lack of appropriate tools that specifically target the challenges faced by the PMOs. Although there are generic modelling platforms available, either Commercially-Off-The-Shelf (COTS) software or tools possessed by DRDC, the associated steep learning curve prevents their adoption in the PMOs.

Secondly, external M&S supports such as those from DRDC were sometimes pursued; however, the response cycle of such supports occasionally does not match well with the project's timeline. The issue is exacerbated by the fact that the PMO's project schedule can itself change rapidly. Therefore, the PMO often hesitates to put effort from outside organizations on its project critical path.

Thirdly, the usefulness of M&S outputs is sometimes questioned. This comment reflects two types of concerns: one is that the findings from M&S are sometimes believed to be common sense solutions; whereas the other points out the results obtained from vigorous M&S investigation may become less significant due to the change of wider system assumptions.

In addition, the cost associated with conducting M&S studies was flagged as a concern. However, it is a minor one compared with the issues raised above.

5.2 M&S solutions

The comments reported in the previous sub-section reflect a strong sense of frustration for the lack of proper M&S support that specifically targets the challenges faced by the PMOs. To resolve the challenges, it is important to recognize that a systematic approach is required and the development and expansion of M&S capabilities is one component of a holistic solution. This report will not provide an exhaustive search for that solution; rather, the following discussion will focus on the M&S capabilities that are central to the objectives of the 14dj ARP.

Generally speaking, the study revealed that M&S can be effectively applied in three phases of acquisition: Options Analysis, Definition, and Implementation. However, the type of M&S support differs as the acquisition process evolves. In options analysis and project definition, due to the lack of system design details, analytical methods and simulation tools that generate models with a high level of abstraction is preferred. In contrast, during the implementation phase, high granularity models with detailed system descriptions are needed. As the study showed, from the PMO's perspective, the M&S capability that targets the implementation phase should put more emphasis on system validation, as opposed to design. The difference is subtle. Generally, functionalities such as rapid prototyping, versatile visualization and performance predicting algorithms (e.g., mental workload models) are considered beneficial for validation purposes.

Additionally, the study confirmed the importance of tool development in supporting M&S. While the S&T community is generally very keen on knowledge generation, software development is sometimes viewed as less scientifically significant. Our study revealed an urgent need to package the research findings, in forms such as theories and algorithms, into useable tools that can be quickly deployed. In many cases, CF SMEs should be involved in the tool development process to fulfill two important functions: provide domain knowledge about CF operations; and suggest ways of integrating the tool's usage into the target client's workflow.

The following is a list of specific ideas on M&S capabilities, raised in the study, that are required to support the navy acquisition projects.

1. *Develop a repository of HF and HSI requirements.* Reviewing system requirements of legacy systems is a useful approach to preserve a necessary level of consistency across CF acquisitions. However, the lack of a standard leads to a circumstance in which the practice is heavily influenced by the personal perspectives of the requirement developers. This issue becomes more prominent for HF/HSI requirements given the many challenges described in Section **4**. A central repository that stores the HF/HSI requirements will greatly assist the PMO. Such a repository should consist of not only a collection of individual HF/HSI requirement, but the category of related requirements as well as sufficient descriptions of the context of each requirement, e.g., the rationale behind it and its applicability. The centralization of such data will also improve their reusability.

2. *Develop tools that support the management of acquisition data throughout the entire acquisition project life cycle*. As shown in *Figure 2*, key acquisition data refer to the system's operational requirements, its technical specifications, and eventually the engineering design solutions. From a data management point of view, the acquisition process can be viewed as a process of generating system operational requirements, translating them into technical specifications and eventually into systems designs. There exists a linkage among requirements, specifications and design. Currently the data are captured in documents such as SOR. Software tools like DOORS® are used to manage technical requirements to an extent; however, there is not a good method or a tool to support the management of HF/HSI requirements.

The issue can be resolved in a number of potential ways. One idea described here involves the full embracing of Mission, Function, and Task Analysis (MFTA) in an acquisition process. As a common approach used by engineers in systems design, MFTA suggests an iterative process in analyzing systems design requirements by breaking down first its mission objectives into supporting functional areas, and then the functional areas into required task activities. The concept can be fitted into the acquisition process. First, the creation of system operational requirements can be obtained by a thorough mission analysis. Then, the development of technical specifications parallels the decomposition of mission objectives into functional areas, from which technical requirements can be derived. Both levels of analysis can be performed by the PMO. When the vendor starts detailed systems implementation, the process inevitably involves some form of task analysis. Under the scheme of MFTA, this can be achieved by further decomposing the functional areas supplied by the PMO.

While the author admits modification of MFTA is likely needed to fully support a PMO's needs, the key concept here is that a comprehensive analytical framework can be adopted for the entire acquisition process. Different stakeholders are responsible for performing a component of the full analysis. In this case, the PD conducts the initial mission analysis and obtains the operational requirements for the planned system. The PM carries on with the mission breakdowns and generates technical specifications based on first identifying the system functional areas and then associating them with technical needs. The vendor completes the analysis by fragmenting the system functional areas into machine and human tasks, based on which design decisions are reached. The benefit of adopting such a unifying analytical framework is at least two-fold: It improves the traceability in the design process. The impact of any change of operational requirement on design choices, or vice versa, can be quickly examined. With the addition of rationales and assumptions in the analysis process, the output from MFTA serves as a complete knowledge base for the acquisition project. Compared with the current practices in which interfacing between stakeholders reflects a stove-pipe structure based on several key project documents, the knowledge-base solution creates a single data repository that provides each stakeholder with a complete picture of the project. It also has the added benefit for PMOs of mitigating the challenges caused by personnel changes, with concomitant loss of project know-how, due to the military posting cycle.

Notably, the central notion of this idea is to adopt a holistic and comprehensive approach to support the acquisition process. Given the complexity of modern military systems, conventional application of M&S is sometimes criticized as providing piecemeal solutions to a large interconnected systems design and development challenge. Without a comprehensive approach, the benefit of M&S is neutralised due to the lack of consideration about the dynamics that exist in the acquisition process. The limitation is more prominent for issues such as HSI where a high level of interconnectedness exists in the design requirement. The issue has to be addressed by using a holistic approach. The selection of MFTA above is only for illustration purpose; there exist other candidate frameworks that may also be used to achieve the same goals, such as the Human Centric Architecture Framework.

3. *Develop tools to support work space analysis and validation.* More specifically, the request for capabilities in spatial layout analysis was made by two naval projects in this survey. The need to support bridge layout design received a high rating score in the SME feedback. Additionally, work space analysis is also reflected in the need to model physical characteristics of the operators

as well. Anthropometric models of the human were specifically mentioned by a CSC SME in the survey.

4. *Develop capabilities in operational scenario generation.* Operational scenarios are proven useful products that are frequently used in an acquisition project. They can be introduced in the early project phase to identify system operational requirements, as well as in the later phase to verify design choices. The current study found out that relatively simplistic scenarios were available for each of the projects at the moment. Strictly speaking, scenario generation is not a pure HSI challenge, however, the author considers it an important activity to enable injection of HF inputs. Although most forms of stressors included in a scenario can eventually be linked to operator performance, it is useful to consider the development of a packaged battery of HSI vignettes that can be easily integrated into larger operational scenarios. This will not only raise the awareness of HSI's importance in system acquisition, it can also provide a baseline for performance measurement if a standardized set of vignettes can be created. It is worthwhile to note that the need for more complex scenarios was recognized by many SMEs in the survey, however, it was not rated as highly important in contrast to other platform directly related design issues.

5.3 Additional insights

Two additional insights were obtained in this study; they are listed in a separate sub-section because they were not directly raised by the SMEs.

1. Modelling the impact of automation use. The new ships will be equipped with a wide array of advanced automation, smart systems and decision aids. The benefit of automation use is generally well understood by the SMEs. For example, automation is considered as a key enabler for crew reduction. However, the full implication of automation use is much more complex. Although some SMEs started to recognize that, the lack of supporting methods and tools make it difficult to fully assess the consequences. Using crewing as an example, it is obvious that automating certain manual tasks alone does not guarantee that associated operators can be eliminated, considering that sailors onboard a ship often assume multiple roles. The use of automation also changes the nature of work an operator performs; unless the human is entirely removed from the task loop, automation tends to reduce the physical effort for a task, but increases its cognitive demand at the same time. This leads to a number of significant implications. Firstly, mental workload analysis becomes more important as operators' performance is increasingly determined by their abilities to conduct cognitive activities like judging, reasoning, decision making and so on. Secondly, competency requirements associated with these tasks start to change and this will affect not only recruitment requirements but training plans as well. Without a full consideration of the impact of automation use, operational difficulties are bound to happen, as supported by anecdotal evidence from allied navies provided by SMEs. Additionally, it is important to consider the consequences of automation failure in systems design and evaluation. Given the adversarial environment in which the warships are designed to operate, this issue becomes even more critical. Analytical methods and tools that assist both the PMO and vendor to conduct risk assessment will be important for addressing the impact of automation.

The challenges around automation use encompass a broad range of issues including hardware, software, and peopleware. The author would argue that HSI is one of the critical, if not the most critical, components in design consideration. With the introduction of intelligent machines, the symbiosis between human and technology becomes increasingly complex. Theoretical issues around topics such as trust between user and automation have not been completely resolved. It is an area that more HF research is needed, including M&S.

2. A System-of-Systems (SoS) approach towards M&S. An interesting finding in this study was that M&S support for the design and evaluation of individual equipment systems was not considered a high priority from the PMO's perspective. The reason is that systems design is mostly performed by the vendor, as is the assessment of individual system components. As a result, the PMO considers the need for M&S support to examine individual component systems as a low priority. In contrast, significant concerns arise regarding system interoperability, particularly the effectiveness of integrating different equipment systems together and its impact on operator performance. There are several levels of HF issues to be addressed here, from the standardization of OMI to operational process optimization. The challenge for the M&S community is to develop capabilities for representing scalable complex systems with interactive components, based on an SoS approach. The achievement of such a goal requires both an advancement of existing M&S theories and software platforms.

One possible solution that was discussed in this study focused on the development and application of architecture frameworks, such as the DND/CF Architecture Framework (DNDAF). It is a common practice in systems engineering to use enterprise architecture for describing a complex system, particularly the structure of system components, their relationships, and the principles and guidelines governing their design and evolution over time. An architecture framework like DNDAF defines a common approach for development, presentation, and integration of architecture descriptions [13]. In DNDAF, such descriptions are organized in the form of various views, e.g., Operational Views (OV), System Views (SV), Technical Views (TechV). For HF issues, a subset of the architecture framework, i.e., the HV, has been created for guiding the description of the human component in a man - machine system. With an integration of HV into the DNDAF, the framework provides a viable solution for creating system architecture models based on an SoS approach.

6 Conclusions

The on-going RCN fleet modernization and replacement projects have brought both opportunities and challenges for HF practitioners. With a goal to develop relevant technologies to support these projects, the current study assisted the 14dj ARP by identifying M&S capabilities most suitable for satisfying the Navy's needs. Although the study focused on maritime platform acquisition, many of the HSI challenges and M&S solutions discussed in this report are also applicable to other CF environments.

Over the years, DRDC Toronto has developed a range of M&S capabilities to address HSI issues, ranging from theoretical frameworks, computational algorithms, to software platforms. While each of them was created to address a specific type of HF challenge, and is important for that purpose, it is arguable that a consistent strategy that explicitly targets a client group is yet to be completed. Fundamentally, the current study is a user needs analysis of the PMOs. The results shed a light on a list of M&S capability gaps that should be addressed in future R&D efforts.

For the 14dj ARP, a decision on future project plans was made to develop and apply the human centric architecture framework, that is, the HV, in the context of JSS. This decision reflects a focus on a modelling methodology that emphasizes the SoS approach. Although architecture frameworks like the HV may not present sufficient levels of detail to support platform design, it is considered the best approach for describing a complex system like the JSS ship and will assist the PMO tasks in the early acquisition phases. JSS was selected primarily because its acquisition timeline best matched that of the 14dj ARP. The longer R&D plan is to verify and validate the HV for JSS, and eventually apply it to the CSC project.

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List of symbols/abbreviations/acronyms/initialisms

ADM(Mat)	Assistant Deputy Minister (Materiel)
AOPS	the Arctic/Offshore Patrol Ship project
ARP	Applied Research Project
CBP	Capability-Based Planning
CF	Canadian Forces
COTS	Commercially-Off-The-Shelf
CSC	the Canadian Surface Combatant project
DAR	Director of Air Requirements
DLR	Director of Land Requirements
D Mar Pers	Directorate of Maritime Personnel
DMR	Director of Maritime Requirements
DND	Department of National Defence
DNDAF	DND/CF Architecture Framework
DRDC	Defence Research & Development Canada
EPA	Effective Project Approval
FOC	Full Operational Capability
HCM/FELEX	Halifax Class Modernization/Frigate Life Extension
HF	Human Factors
HFE	Human Factors Engineering
HMG	Human Modelling Group
HSI	Human Systems Integration
HV	Human Views
JSS	the Joint Support Ship project
K/S/A	Knowledge/Skills/Abilities
M&S	Modelling and Simulation
MFTA	Mission, Function, and Task Analysis
MOTS	Military-Off-The-Shelf
OMI	Operator Machine Interface
OV	Operational Views
PCR	Project Completion Report

PD	Project Director
PM	Project Manager
PMO	Project Management Office
PPA	Preliminary Project Approval
PPRA	Project Profile and Risk Assessment
R&D	Research and Development
RCN	Royal Canadian Navy
RFP	Request For Proposal
S&T	Science and Technology
SME	Subjective Matter Expert
SOR	Statement of Operational Requirement
SoS	System of Systems
SS	Synopsis Sheet
SS(ID),	Synopsis Sheet (Identification)
SS(EPA)	Synopsis Sheet (Effective Project Approval)
SS(PPA)	Synopsis Sheet (Preliminary Project Approval)
SV	System Views
TechV	Technical Views

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This report summarizes a series of surveys to understand the Human Systems Integration (HSI) challenges encountered in major Canadian Forces (CF) capital acquisition projects and the role of Modelling and Simulation (M&S) as a potential solution. The study targeted three on-going naval platform acquisition effort, including the Joint Support Ship project (JSS), the Arctic/Offshore Patrol Ship project (AOPS), and the Canadian Surface Combatant project (CSC). Subject Matter Experts (SME) from these three projects as well as other key stakeholders in the acquisition process were interviewed. The study reviewed the standard Department of National Defence (DND) procurement process, examined the HSI challenges in each phase of the process and their implications on M&S capability requirement. The results identified a list of key challenges prioritized in the context of JSS, AOPS and CSC, and, correspondingly, the M&S capabilities required to address these challenges. In particular, the development of a human centric architecture framework and its application in the JSS were rated as top priority. The findings assisted the finalization of research objectives for a Defence Research and Development Canada (DRDC) Applied Research Project (ARP) 14dj.

Le présent rapport résume une série d’études visant à améliorer la compréhension des défis en matière d’intégration des systèmes humains (ISH) que posent les principaux projets d’acquisition d’immobilisations des Forces canadiennes (FC), ainsi que du rôle de la modélisation et de la simulation (M & S) comme solution potentielle. Ces études visaient trois projets d’acquisition de plates-formes navales en cours, notamment les projets d’acquisition de navires de soutien interarmées (NSI), de navires de patrouilles extracôtiers de l’Arctique (NPEA) et de navires de combat de surface canadiens (NCSC). On a interrogé des experts en la matière (EM) de ces trois projets ainsi que d’autres participants clés au processus d’acquisition. Dans le cadre de ces études, on a passé en revue le processus d’approvisionnement standard du ministère de la Défense nationale (MDN) et examiné les défis en matière d’ISH de chaque phase du processus, ainsi que leurs répercussions sur l’exigence relative à la capacité M & S. Les résultats obtenus ont permis de dresser une liste des défis clés priorisés dans le contexte des NSI, des NPEA ainsi que des NCSC et, par conséquent, des capacités M & S requises pour relever ces défis. En particulier, l’élaboration d’un cadre d’architecture centré sur la personne et son application en ISH ont été cotées « priorité absolue ». Les conclusions ont aidé à l’atteinte des objectifs de recherche d’un Projet de recherches appliquées (PRA) de Recherche et développement pour la Défense Canada (RDDC), vecteur 14dj.

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Modelling and simulation; Human systems integration; Navy platform acquisition

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