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A Systems Approach to Naval Crewing Analysis: Coping with Complexity

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As the Royal Canadian Navy (RCN) transitions to the Arctic Offshore Patrol Ship (AOPS), the Joint Support Ship (JSS) and the Canadian Surface Combatant, any decisions on crew size and composition will have significant impact on both total ownership costs and operational capabilities. In 2000 the US Naval Research Advisory Committee determined that 70% of total ownership cost is due to operations and support and 51% of the operations and support cost is tied to personnel, which suggests that reducing crew size can result in significant cost savings.[1] However, the US Navy's (USN) recent experience with the Littoral Combat Ships (LCS) suggests that these ships, which were designed to have very small crews, may present significant risks for manning and logistics (i.e., high workload and inadequate sleep for the crew, and inadequate shore support), and maintenance.[2] The US General Accountability Office (GAO) now estimates that "the annual per ship costs for LCS are nearing or may exceed those of other surface ships, including those with greater size and larger crews, such as frigates."[3]

The challenge, therefore, is to design ships with the right-sized crew, especially because decisions made in the design phase are estimated to lock in 80-90% of the procurement and operating and support costs.[4] If the crew size is over-estimated in the design phase, then design and build costs may be inflated by the need for additional crew accommodation. If the crew size is under-estimated, then the platform may fall short in operational capability or readiness, and there may be limited feasibility, significant

Credit: Mass Communication Specialist 1st Class James R. Evans USN

*The Littoral Combat Ship USS **Freedom** (LCS 1) during sea trials, 22 February 2013. The ships were planned to have a 3:2:1 manning concept – i.e., three ship crews and two hulls for each ship on station at any time. The other ship and other two crews not on deployment would be either preparing for deployment or in rotation in or out of theatre. It was hoped that the net result would be a 50% reduction in ships and a 25% reduction in crews than traditional deployment practices.*

costs, or delayed schedules associated with subsequent design changes.

Determining the right-sized crew early on in ship design has several key challenges:

- technology decisions may not have been made (e.g., availability of automated storing capability would affect the number of crew required to support replenishment at sea);
- policies and procedures are evolving (e.g., will Naval Boarding Parties be an integral capability built into each ship's crew, or will they be brought on as required as part of a mission fit?); and
- military occupational structure is evolving (e.g., who will operate unmanned air or underwater vehicles from a naval platform? Will there be common operators across all warfare areas?).

In the past four years, Defence Research and Development Canada (DRDC) has worked closely with the RCN to develop a systems approach and a decision support tool to conduct crewing analysis for naval platforms. The tool, called Simulation for Crew Optimization for Risk Evaluation (SCORE), supports what-if analysis on whole ship crewing by:

- identifying and exposing factors that are relevant to crew size and composition;
- supporting the RCN in explicitly defining and combining the current assumptions on the relevant factors;
- supporting the RCN in systematically evaluating and comparing the impact of these assumptions; and
- enabling the RCN to modify these assumptions as new information becomes available, and to modify the crew estimate as required.[5]

Credit: DND

Artist rendering of the definition design for the RCN's Joint Support Ships showing two Replenishment at Sea (RAS) stations.

The purpose of this systems approach is to support an informed crew estimate at any point in the design process, even when there are information gaps and uncertainty. This approach recognizes that a crew estimate is essential to decision-making and planning, that every estimate should be based on clear and documented assumptions, and that assumptions are subject to change and the estimate must be modified accordingly.

Platform design decisions determine what roles are required within the crew. A supply ship with four Replenishment at Sea (RAS) stations, for example, may require a minimum of four RAS teams, whereas a ship with only two RAS stations may need fewer RAS teams. Similarly, the location of ship compartments may affect crew requirements. Where combat systems that require the same expertise are located in close proximity, for example, fewer repair teams may be needed to provide adequate coverage for all systems. Once a platform design is assumed, the number and types of special teams can be defined, followed by the number of roles within each team and the qualifications (i.e., occupation, level of training) required for these roles.

The decision to invest in certain technologies also determines which roles are required within the crew. For example, the type and degree of automation available to support RAS may dictate the number of line handlers or winch operators required to conduct RAS. The availability and reliability of remote sensors, remote actuators and remote monitoring for the combat systems or for the engineering plant will influence the human tasks and will, in turn, influence the number of crew and the required qualifications. Once specific technologies are assumed, a specific number of roles can be defined for the crew to operate and/or maintain these technologies, and the qualifications can be defined for each role.

Although warships remain exempt from civilian maritime regulations, the regulations enacted by the International Maritime Organization (IMO), such as the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), and Transport Canada's marine personnel regulations must be considered when designing crew sizes and composition. There are also RCN directives that define the size and composition of special parties, such as Section Base Teams, Emergency Repair Teams and Casualty Clearing Teams, during emergency situations. As technologies, such as the Integrated Platform Management Systems, and practices, such as damage control procedures, evolve in domestic and international maritime operations, policies and procedures will also be revised. Roles for watchkeeping or for special parties need to be defined by assuming the practices described in current publications, but these roles and their qualifications may need to be redefined when new publications are drafted.

As the RCN adapts to challenges in recruiting, retention and force generation, options that will optimize the use of personnel, such as the amalgamation of trades and the reassignment of duties and training must be considered. To propose crew sizes and composition for future platforms, some assumptions must be made on the required qualifications (e.g., any trade required, a specific occupation, or one of several occupations) for each role that is defined for watchkeeping, maintenance, special parties, or departmental work, based on the current or planned military occupational structure. These objective assumptions can be used to propose a crew but there are other factors that must be considered in, or that may be affected by, crew composition. Perhaps most critical is force generation. In the AOPS instance, the RCN determined that, while a smaller crew of 'seasoned' sailors could effectively operate the ship, a small crew of experienced sailors afforded no opportunity to develop the next generation of sailors.

Similarly, crew composition must align with, or cause to change, the occupation structure of the RCN and its existing allocation of skills and tasks. This can, at times, result in an arbitrary requirement for a specific occupation and, thus, drive crew composition. It is critical that proposed crew compositions are based on an objective assessment of requirements because this provides a basis on which the RCN can make informed crewing decisions.

SCORE Crew Validation and Generation

Figure 1 depicts how a proposed crew size and composition (i.e., a 'crew manifest') is validated using SCORE, and how different proposals are compared. SCORE enables RCN stakeholders to make explicit and documented assumptions about platform design, technology, policies and procedures, or personnel, by defining specific roles that must be filled by the crew, and specific qualifications for each role. For example, two different sets of roles (each called a 'configuration') can be defined. One configuration may assume existing automation, and another configuration may assume advanced automation, which may have fewer but different roles for the crew. A new configuration (i.e., a set of roles associated with a set of activities) can also be created to combine assumptions (e.g., advanced automation with current damage control procedures versus advanced automation with revised damage control procedures). The user can provide one or more scenarios (i.e., schedule(s) of activities) based on assumptions of different operational requirements (e.g., for a high readiness ship versus a standard readiness ship).

The user can then assign specific members of the proposed crew to specific roles in the selected configuration. SCORE provides feedback on the crew in terms of conflicts (i.e., whether the same crew member needs to perform two or more concurrent but incompatible duties in the scenario), and utilization (i.e., how much time each crew member needs to perform duties in the scenario). Critical crew conflicts, and very high or very low utilization would indicate problems with the proposed crew. A change to the crew size, crew composition and/or role assignments

Figure 1. SCORE Crew Validation

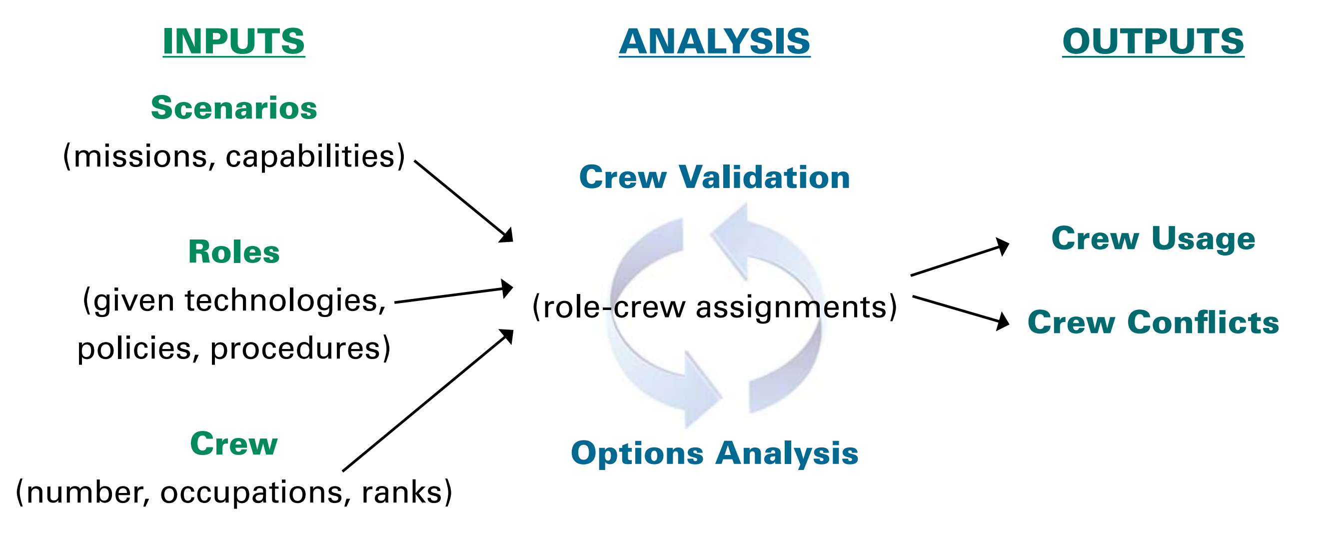
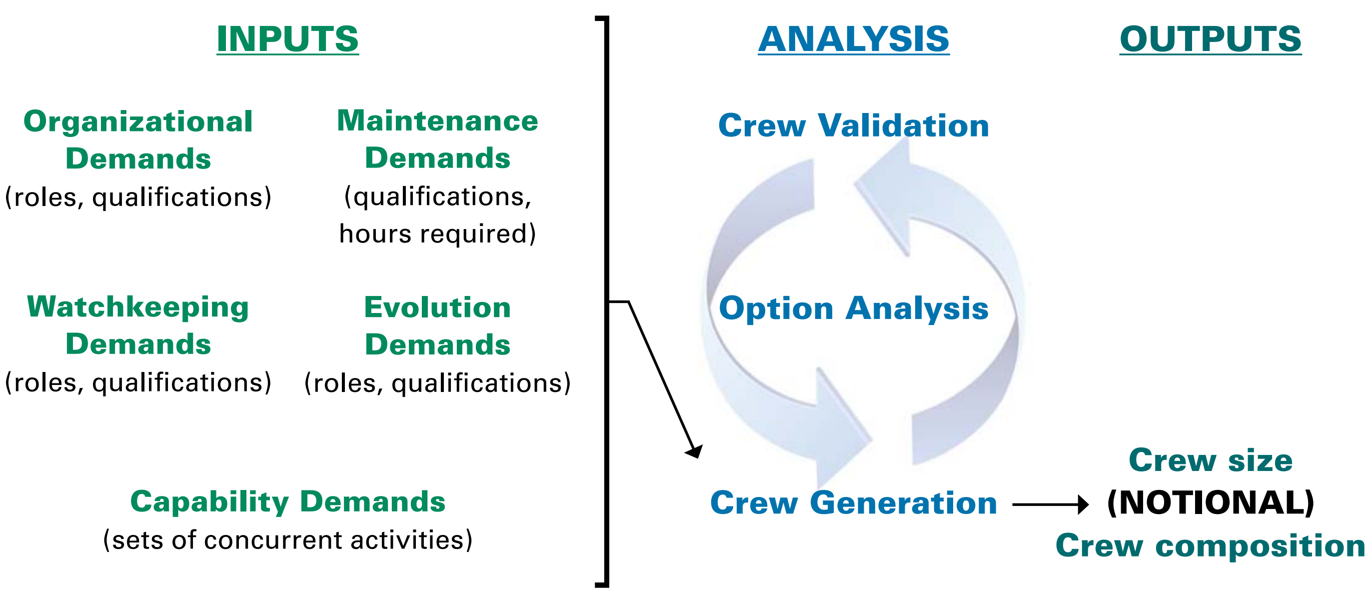


Figure 2. SCORE Crew Generation



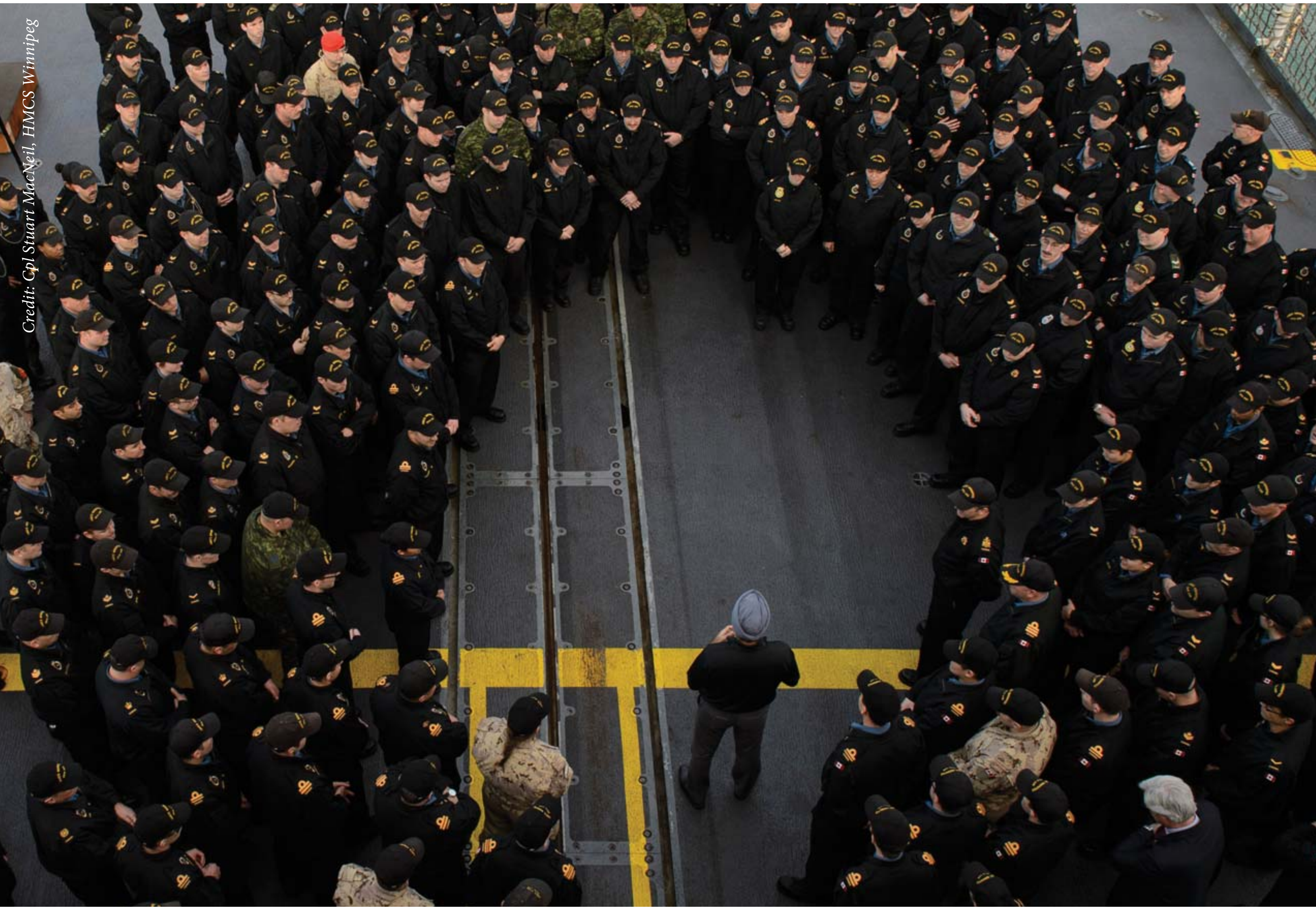
may be required, or the existing assumptions may need to be revisited.

Figure 2 depicts how a notional crew is generated using SCORE. Like in crew validation, users would define required roles and qualifications based on assumptions about platform design, technology, policies and procedures, and/or personnel. These roles would reflect organizational demands (e.g., Commanding Officer, Coxswain, firefighters, cooks), watchkeeping demands for each ship department, maintenance demands, which may include preventive and/or corrective maintenance and/or first-line and/or second-line maintenance, as well as demands associated with single evolutions and concurrent evolutions (e.g., the capability to perform a fueling RAS at the same time as a solid cargo RAS, or the capability to enter harbour at the same time as conducting force protection). The user can also choose to consider only a subset of the demands (e.g., exclude maintenance in a given phase of analysis).

Similarly, the user can select different combinations of assumptions to generate different notional crews for comparison. For example, a notional crew can be generated based on a watchkeeping demand where every department would stand a 1-in-2 watch, versus a watchkeeping demand where some departments will stand a 1-in-3 watch. The result will be different notional crews of different sizes and different compositions, based on the combination of demands that are selected. One or more of these crews can be selected for further examination and refinement, and can, eventually, be subjected to a validation analysis based on one or more scenarios, therefore completing a full-cycle crewing analysis that includes crew generation, crew validation of either a single crewing solution or comparison of multiple possible crewing solutions.

As decisions are made during the ship design process, it is possible to replace assumptions with known inputs (e.g., the new RAS equipment will need six people to operate) or to trial different combinations of known inputs and remaining assumptions (e.g., the size of RAS team is known but the size of Section Base teams is still subject to change and two options are being considered). As well, it is possible to examine the effects, if any, in terms of crew conflicts and crew utilization (e.g., a smaller RAS team can mean a smaller overall crew size because the primary and secondary duties of the original RAS team members can all be reassigned to other members of the crew, or perhaps not).

One of the key considerations when determining crew sizes for future platforms is whether the future crew, which is likely to be somewhat reduced in size given enhanced technologies, can maintain and sustain high levels of performance. For example, will a smaller crew mean that the same crew members have to take on many more primary and secondary duties, such that they experience fatigue and reduced cognitive effectiveness? There are ongoing efforts by DRDC to integrate a predictive



Credit: Cpl Stuart MacNeil, HMCS Winnipeg

*The Honourable Harjit S. Sajjan, Minister of National Defence, addresses the ship's company of HMCS **Winnipeg** on the flight deck during his visit to the ship on 23 December 2015 during **Operation Reassurance**.*

model of crew performance into SCORE, and a proof-of-concept prototype has been produced and demonstrated to the RCN.[6]

Essentially, based on the scenario and the crew assignments, SCORE currently produces a predicted work schedule for each crew member for the modeled scenario. The new crew performance model translates the predicted crew work schedule into a predicted crew sleep schedule, then predicts crew cognitive effectiveness based on the predicted crew sleep schedule. The algorithm for sleep to cognitive effectiveness prediction has been validated against the state-of-the-art and commercially available Fatigue Avoidance Scheduling Tool (FAST)[7] that is widely used in the aviation and transportation industries, and was used to evaluate watch schedules for RCN submarines and frigates.[8] The current research at DRDC focuses on the validation of the work to sleep prediction through data collection on a RCN platform.[9] It is expected that the ability to consider crew fatigue and performance in crewing analysis will be available by 2016 and will provide an additional layer of analysis in determining crew size and composition.

Alternatives to SCORE

The United States and the United Kingdom have also developed software tools to facilitate crewing analysis. The US IMproved Performance Research Integration Tool (IMPRINT) Pro is a "dynamic, stochastic, discrete event network modeling tool"[10] that has been used to analyse different crews for the LCS. The IMPRINT Pro Forces module allows the user to define complex characteristics and relationships for activities and different schedules for crew members and, through modeling, reports on activities that have failed during the analysed period.[11] IMPRINT Pro seems to be more able to deal with complexity than SCORE when validating crew size and composition but, because it is probabilistic, it may be difficult to anticipate and track how an assumption made in one part of the model will interact with other parts of the model to affect the outcomes. The United Kingdom's Complement Generation Tool (CGT) is similar to SCORE in that it generates a crew from particular watch states, which include requirements for equipment manning, watchkeeping, evolutions and maintenance.[12] Unlike SCORE, though, CGT does not seem to support crew validation.

DRDC Toronto developed SCORE to allow the RCN to model and validate crew constructs and, although the software is still being refined, the Directorate of Naval Personnel and Training (D Nav P&T) has used SCORE as a crew modeling tool since 2012. Three projects, in particular, are illustrative. First, in 2013, D Nav P&T used the crew validation module of SCORE to analyse proposed changes to the *Halifax*-class frigate crew. In this study, the existing crew of 200 was compared to a crew of 217 by modeling each of the ship's departments (excepting the Air Department) against a 10-day Phase III work-ups scenario. Interestingly, while the usage rates of sailors was not significantly different, the model illuminated roles that were not being filled in the smaller crew.

Second, D Nav P&T used the crew validation module to assist in determining the appropriate crew size for the *Harry DeWolf*-class AOPS.[13] In this instance, analysts were able to use SCORE to prove quantitatively that original crew estimates were too small to cover the range of capabilities the new platform was meant to provide, thereby justifying a more realistic crew size and composition that would more appropriately balance capability and cost. Finally, the RCN is using the crew generation algorithm to develop a crewing proposal for the JSS. Fundamentally, the crew generation module, with its enforced methodology of inputting organizational demands, watchkeeping demands, maintenance demands and then evolution demands, matches qualifications to requirement. This forces the consideration of non-traditional role assignments and facilitates optimizing of personnel.

Conclusion

The RCN has adopted an iterative, consultative, whole-ship and multi-faceted approach to crewing analysis for naval platforms. In the face of many sources of uncertainty related to platform, technology, policies and procedures, and personnel, it may not be possible to determine, at the design phase, an optimal crew size for a future ship. However, by relying on explicitly documented yet modifiable assumptions, and a systematic approach to conduct both crew generation and crew validation and the systematic comparison of possible crewing options, it is possible to develop crewing proposals that provide rational and defensible foundations on which to base decisions that consider all personnel factors.

Notes

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11. In IMPRINT Pro Forces, the user is able to define probability distributions for activity start-time and duration, a 'trump matrix' to define relative priorities of activities, an 'interrupt strategy' to define what happens when a higher priority activity is encountered, and the effect of adding crew members such as reducing activity time by a certain percentage.
12. G. Merrett and N. Bailey, *Complement Generation Tool: User Guide v 3*, 2008, QINETIQ/EMEA/TS/UG0800118/3.0. QinetiQ; and W. Wang, "Functionality and Usability Assessment of the Complement Generation Tool (CGT): A Preliminary Review," DRDC Toronto TM 2011-057, April 2011.
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