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EXERCISE, EXERCISE, EXERCISE: Making effective use of joint training funds

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IMPORTANT INFORMATIVE STATEMENTS

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Abstract

Joint exercises are vital to the Canadian Armed Forces (CAF) meeting their readiness targets. However, CAF resources are often insufficient to participate in all candidate joint exercises, which posed a research question: *how can the CAF get the most value out of its joint training resources?* Using strategic analysis and operations research, we designed a value model to gauge a joint exercise's value and an optimization model to support decision makers when selecting a joint exercise portfolio. This scientific report describes these models, presents an example of their application, discusses challenges encountered with their application, and provides recommendations aimed at overcoming them.

Significance for defence and security

The work's significance is that it provides the Canadian Armed Forces' Joint Training Authority an approach that greatly enhances its ability to construct, characterize, and adjust the Joint Managed Readiness Program's exercise portfolio. As such, the approach described herein lays a solid foundation on which joint training resources may be best utilized in accordance with real-world constraints.

Résumé

Les exercices interarmées sont essentiels pour que les Forces armées canadiennes (FAC) puissent atteindre leurs objectifs de préparation opérationnelle. Toutefois, les ressources des FAC sont souvent insuffisantes pour participer à tous les exercices interarmées proposés, ce qui a mené à une question de recherche : Comment les FAC peuvent-elles profiter au maximum de leurs ressources d'entraînement ? Au moyen d'une analyse stratégique et d'une recherche sur les opérations, nous avons conçu un modèle de valeur pour juger de la valeur d'un exercice interarmées, et un modèle d'optimisation pour appuyer les décideurs au moment de sélectionner le portefeuille d'un exercice interarmées. Le rapport scientifique décrit ces modèles, présente un exemple de l'application, discute des difficultés vécues dans l'application, et fournit des recommandations pour surmonter ces difficultés.

Importance pour la défense et la sécurité

L'importance de cette étude réside dans l'approche qu'elle procure au responsable de l'entraînement interarmées des Forces armées canadiennes pour grandement augmenter sa capacité de concevoir, de caractériser et d'ajuster le portefeuille d'exercices du programme de préparation opérationnelle interarmées. Ainsi, l'approche décrite dans le rapport établit une solide fondation grâce à laquelle les ressources d'entraînement interarmées peuvent être utilisées au mieux selon des contraintes réelles.

Table of contents

List of figures

List of tables

Acknowledgements

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1 Introduction

Militaries train to enhance their readiness in order to be prepared to meet operational demands. Although each military prepares for such demands differently (see [1] for several examples), training typically occurs through the process of force generation.[1] While each type of training plays an important role, joint training has been identified as key to improving the interoperability between military services [3, 4], building capacity between partner forces [5], and as a major factor in the successful prosecution of wars [6].

Within the Canadian Armed Forces (CAF), the Commanders of the Royal Canadian Air Force, Royal Canadian Navy, Canadian Army, and Canadian Special Operations Forces Command are the functional authorities for their respective (service-specific) force elements and, as such, are responsible for bringing these elements to the readiness standards specified in the Chief of the Defence Staff (CDS) Force Posture and Readiness (FP&R) Directive.[2] In turn, the CAF's Joint Training Authority (JTA)—Commander Canadian Joint Operations Command (CJOC)—is responsible for developing a joint training program that takes the first three service's force elements (i.e., Canadian Special Operations Forces Command conducts joint training, although it does so autonomously) to an enhanced state of joint readiness.[3]

Given this responsibility, the JTA produces two documents collectively known as the Joint Managed Readiness Program (JMRP). Volume 1 provides policy and guidance on the conduct of joint readiness training and is updated as required [8]. Volume 2 describes specific activities that are planned to occur over a five-year period, where the first three years include detailed instructions on specific training joint objectives and exercises, and the remaining two years are described in more general terms of intent [9].[4] Volume 2 is updated on an annual basis, and is thus considered a rolling plan.

The JMRP Volume 1 describes several overarching principles that the program must adhere to, including [8]:

- focus on readiness to support Contigency plans (CONPLANs);

[1] *Force generation* may be defined as the process of organizing, training, and equipping forces for force employment [2]. It can include *individual training* to acquire and maintain sufficient knowledge and skill throughout one's career; *collective training* designed to prepare teams, units, and other elements within a single military service to perform specific tasks; *joint training* of a force comprised of elements from two or more services operating under a single commander, etc.

[2] The CDS issues an annual, classified FP&R Directive that directs the force generation of force elements required to deliver operational output aligned to the policy objectives of the Government of Canada. The CAF defines readiness as the preparedness to respond to government direction, expressed in terms of two basic components: the capability (force element) to execute a military task (effect) and the time to deploy the capability (speed) to perform a specified tactical or operational task. For a detailed discussion of readiness as a function of effectiveness and speed of response, see [7].

[3] Joint training is, according to CJOC: "an activity that prepares individuals, joint staffs, or joint forces to respond to strategic, operational, or tactical requirements to execute their assigned or anticipated missions" [8]. The JTA defines joint readiness as a "state of preparedness, validated against the [CAF] Joint Task List, for a joint force assigned to an operational task" [9].

[4] The North Atlantic Treaty Organization (NATO) defines an exercise as: "A military manoeuvre or simulated wartime operation involving planning, preparation, and execution. It is carried out for the purpose of training and evaluation. It may be a combined, joint, or single service exercise, depending on participating organizations" [10].

- emphasize critical capabilities (cyber, space, information operations, etc.) and joint enablers (command and control, communications and information systems, operational support);
- be based on a series of integrated activities that achieve an enhanced state of joint readiness;
- concentrate on force elements that need to be integrated as detailed in the FP&R;
- ensure that global engagement opportunities with partners and allies are taken into account; and
- validate the force elements' readiness against the CAF Joint Task List—a menu of tasks, described in a common language, that, amongst other things, enable standards to be applied to joint training.

Developing a program that respects these principles, while simultaneously not exceeding the financial constraints imposed by the Joint Exercise Training Allocation (JETA)—the JMRP's primary funding source—is not a straightforward procedure. Historically, the program's development and refinement occurred through collaborative discussions between JTA staff, exercise planners, and subject matter experts. This has proven to be resource intensive, in both terms of time and effort. There are three reasons for this. First, the number of candidate joint exercises to be considered in each fiscal year is on the order of 50–100, which makes the set of potential joint exercise portfolios too large to consider manually in any great detail. Second, the cumulative fiscal demands of the candidate joint exercises in any given fiscal year far exceed the annual JETA funding, which is typically on the order of $30–50 million. Lastly, the lack of defined criteria to assess the value of a joint exercise to the CAF makes it difficult to determine the opportunity cost of including/excluding an exercise in the program.

Given these challenges, JTA staff requested that CJOC Operational Research and Analysis (OR&A) design and implement an approach to support the development and refinement of a five-year rolling exercise program consistent with government policy and force posture direction. Based on several consultative meetings between JTA staff and CJOC OR&A during the period November 2016 through February 2017, the following problem statement was developed, and was subsequently endorsed by Commander CJOC [11]:

> To provide a rigorous means of selecting a set of joint exercises that can be conducted in a given period optimally aligned with government policy and force posture direction, subject to the constraints required of the JTA:
>
> - all CONPLANs (for which opportunities exist) must be exercised at a specified frequency;
> - all tasks in the joint task list (for which opportunities exist) must be provided an opportunity to be validated at a specified frequency;
> - all geographic regions (for which opportunities exist) must have at least one exercise conducted within their boundaries at a specified frequency; and
> - the sum of the selected exercises' costs in each fiscal year must not exceed the available JETA budget in that fiscal year.

This scientific report describes the approach designed and implemented by CJOC OR&A in response to this problem statement. The main contributions of this work are as follows.

1. A value model, designed using a strategy-to-task approach, that consists of a set of criteria that can objectively assess the value of joint exercises to the CAF (Section 2.2).

2. An optimization model whose objective is to build a balanced portfolio of joint exercises optimally aligned with Government of Canada and force posture direction, while respecting a set of real-world constraints (Section 2.3).

The remainder of the report contains four main sections as follows. Section 2 lays out the design of the value and optimization models, as well as the process used for data collection. Section 3 details how the value model's criteria weights were set, an exploratory analysis of the data used within this report, and an example application of the optimization model to that data. Section 4 identifies challenges encountered in developing and using the models, and provides recommendations both for short- and long-term solutions to those challenges. Finally, Section 5 highlights the most pressing issues, and identifies practical opportunities to extend and enhance the model implementation. Technical details of the current implementation are available in a separate document [12].

2 Methods

This section presents the value model that is designed to objectively assess the value of joint exercises to the CAF and the optimization model whose purpose is to build a balanced joint exercise portfolio. In addition, we discuss the process to collect the necessary data to employ both these models. However, we begin with an overview of how these three components work together to support the development of a joint exercise program.

2.1 Overview

As described in Section 1, the objective of the JMRP is to develop a five-year joint exercise plan that is updated on an annual basis. This is executed through an annual business planning process, depicted in Figure 1, and is broadly described as follows:

Step 1 – In preparation of an exercise plan for a coming fiscal year, data about candidate joint exercises (i.e., costs, schedule, CONPLAN to be exercised, etc.) is (a) compiled and (b) evaluated by the JTA staff in the preceding fiscal year.

Step 2 – Following the data collection process, (a) the Strategic Joint Staff, who are responsible for JETA governance, determine in consultation with the JTA staff the amount of JETA funding available in the upcoming fiscal year and those joint exercises that will receive JETA funding. Subsequently, (b) the JMRP Volume 2 is updated accordingly.

Step 3 – In the next fiscal year, joint exercises that received JETA funding conduct their activities. Step 1 is reinitiated.

This work's main contributions, the value model and optimization model, provide decision support respectively in steps 1(b) and 2(a). These contributions are discussed in Section 2.2 and Section 2.3 respectively.

2.2 Value model

As part of the effort to provide a rigorous means of selecting a set of exercises that can be conducted in a given period optimally aligned with government policy and force posture direction, six criteria have been selected in consultation between the CJOC OR&A team, the Policy Advisor (POLAD) group at CJOC and the JTA staff. The process of selection, which was iterative and involved frequent consultations among the three groups listed above, aimed to select criteria that were exhaustive (in terms of evaluation), mutually exclusive (in terms of that criteria do not overlap), and operable (in terms of that data is available and criteria will be interpreted by different individuals in the same manner) [13].

This subsection explains the value model and the relative weights assigned to its criteria. The value model, encompassing both government policy priorities and operational readiness requirements, has been developed primarily through strategic analysis, specifically using an approach known as

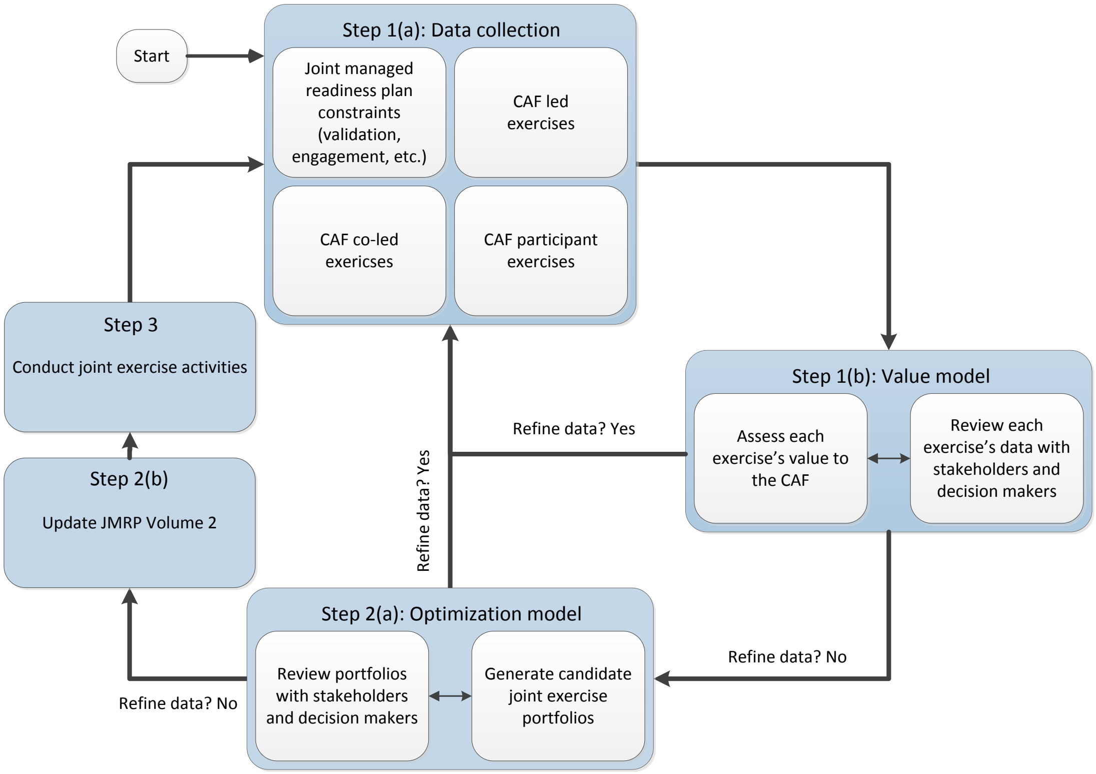


Figure 1: *Overview of JETA business planning process.*

"strategy to tasks" methodology for resource allocation first developed by the RAND Corporation in the 1980s and 1990s.[5]

Through discussions with the JTA staff and based on a review of the JMRP [8, 9], it became apparent that there were two broad categories of direction and guidance that the JTA had applied informally to assess an exercise's value. These categories are *policy priorities* and *operational readiness requirements*. The insight gleaned from this initial investigation informed the following three-step process to identify the eventual six criteria. In step one, relevant national policy-level documentation—e.g., policy statements, ministerial direction, etc.—as well as readiness, training, doctrine and exercise literature used by the JTA was identified and reviewed. This material was examined to develop an understanding of Canadian Government and military priorities on types of conflicts and missions for which the CAF must prepare (train), as well as any direction on partner and geographical preferences (i.e., United States (US) forces, NATO, etc.). Step two involved the identification of six possible policy and operational readiness criteria that could be used to inform exercise selection,

[5]Strategy to tasks methodology, sometimes called *STT* or *S2T*, "links resource decisions to specific military tasks that require resources, which in turn are linked downward hierarchically from higher-level operational and national security strategies to supporting programs and tasks" [14]. See also [15, 16, 17].

based on a review of the above documentation. In the third and final step, the CJOC POLADs and JTA staff were asked to review and validate, respectively, the policy and operational readiness criteria. At this stage the criteria were set, although as indicated above, the definitions were later refined for clarity, and one additional level was added with a single criterion.

2.2.1 Political–Military criteria

The first three criteria—Government of Canada (GC) Interest, Partnering with Actors External to the Department of National Defence, and Exercise Focus—relate to the GC Policy level, sometimes called National Strategic or Political–Military (Pol–Mil) level Direction. As such, the POLAD was asked to evaluate these three criteria. There is some overlap between the criteria but they are sufficiently distinct to evaluate the exercises on the basis of national strategic direction (see Section 3.2.3). The initial assumption, subsequently confirmed by the POLAD, was that there was a relative ranking of importance among these three Pol–Mil criteria. Thus, they have been ranked in the following, descending order of importance: GC Interest (high); Partnering (medium); and Exercise Focus (low). The rationale is that an explicit GC articulation (i.e., the exercise is named explicitly in GC policy or strategy documentation or is strongly in line with GC intent) represents a clear indication of the exercise's importance to the government. Canadian governments have traditionally adopted a concentric circle concept for Canadian defence interests and priorities (discussed below). Likewise, successive Canadian governments have indicated that certain external partners are more important than others to National Defence. Finally, the current Canadian Government, like previous ones, has indicated that defence of Canada and the North American continent are relatively more important than other geographical defence imperatives. Therefore, it is reasonable to conclude that exercises that emphasize the defence of Canada and North America have a higher value than other exercises with a different geographical focus.

2.2.1.1 GC Interest

Defined as the level of interest the GC has in the exercise being conducted, this criterion takes into account the value, as judged by the POLAD, placed on the exercise by outside entities, including NATO, the United Nations (UN) and American organizations. This criterion includes four following levels of interest:

- **Explicit**: Exercise is specifically named in GC/Department of National Defence (DND) policy and strategy documents—the exercise is named, for example, in the Defence Policy Strong, Secure, Engaged (SSE) [18]—or has been identified in ministerial direction such as speeches and correspondence (e.g., a speech by the Prime Minister (PM), the Minister of National Defence (MND) or the Minister of Global Affairs Canada (MINA) that identifies the need for CAF participation in specifically-named exercises in country *X* or region *Y*);

- **Important**: Exercise is consistent with GC interest such as deepening engagement with the Association of Southeast Asian Nations (ASEAN), or relates to existing Alliance commitments and Defence Treaties such as North American Aerospace Defence Command (NORAD) and NATO, or correlates to a specific SSE Initiative but the exercise itself is not specifically named (e.g., SSE initiatives 106 and 110 on Arctic exercises).[6] As another example, SSE Initiative 15 on page 6 states: "Augment the CAF Health System to ensure it meets the unique needs of our personnel with efficient and effective care, anywhere they serve in Canada or abroad. This includes growing the Medical Services Branch by 200 personnel" [18]. Therefore, an exercise that either augments the Health System capacity or enhances its capability to meet the needs of CAF personnel would yield an assessment of Important. CDS direction on CAF participation in exercises would also produce an Important rating;

- **Indirect**: Exercise is not explicitly named in GC/DND documentation or ministerial direction and does not correlate to a specific SSE Initiative but may support an engagement objective. For example, the exercise involves some members of ASEAN but is not an ASEAN exercise, or involves multilateral organizations such as the Conference of the Defence Ministers of the Americas; and

- **Negligible**: No indication or articulation of GC interest in the Exercise.

2.2.1.2 Partnering with Actors External to DND

This criterion refers to the type of partnering with outside actors that occurs in the exercise, including: Other Government Departments and Agencies (OGDs); United States; Five Eyes (FVEY) specifically United Kingdom (UK), Australia and New Zealand; NATO (other than US and UK); and other nations. Similar to the Exercise Focus, this criterion seeks to determine the relative importance of potential partners (e.g., an American partner is more important than one from some other country). The relative rankings have been set by the POLAD and are in the following descending order of priority: 1) OGDs; 2) US; 3) FVEY; 4) NATO; and 5) Others.

The POLAD has further explained that OGDs are specified as being at the highest level as their involvement suggests a defence of Canada or national emergency scenario, implying a high level of GC priority. In terms of exercises involving US and NATO partners, it is important to note the distinction between exercises organized and led by American or NATO military commands and those in which American or NATO partners are simply participating. To be clear, exercises organized and led by American or NATO military commands have a higher value than those in which Americans or NATO are purely participants. For instance, if Americans are simply participants in an exercise then it is scored as Others in terms of partnering. In addition, exercises that are led by NATO country members would be considered NATO exercises, even if NATO as an organization is not running the exercise. Finally, as both the US and UK are members of both NATO and FVEY, an exercise led by the US or UK would be rated respectively as a US and FVEY Partnership opportunity.

[6] The importance of Arctic Exercises to the Government of Canada, including potential exercise partners, can be clearly seen in SSE Initiatives 106 and 110: "Enhance the mobility, reach and footprint of the Canadian Armed Forces in Canada's North to support operations, exercises, and the Canadian Armed Forces' ability to project forces into the region" (106); "Conduct joint exercises with Arctic Allies and partners and support the strengthening of situational awareness and information sharing in the Arctic, including with NATO" (110) [18].

2.2.1.3 Exercise Focus

The geographic focus of the exercise—that is to say, if it is intended to exercise domestic, continental or expeditionary operations. This criterion seeks to apply a concentric circle concept to the geographical basis of the exercise. The concentric circle concept is divided into inner, secondary and outer circles. In terms of Canadian defence priorities, the inner circle can be considered Canada's territory and air and maritime approaches. North American continental defence can be considered secondary but almost on an equal footing as the defence of Canada. The outer circle represents the contributions to international security. These circles are both geographical and conceptual, implying a descending scale of priority as one moves from the inner circle to the outer one. The rankings of the concentric circles from domestic (inner) to expeditionary (outer) have been confirmed by the POLAD. Some exercises have more than one geographic focus and are categorized on the basis of their highest ranking focus (i.e., exercises that have both a domestic and expeditionary focus are designated as domestic). Additionally, there are cases when an American command conducts an exercise but the geographic focus is not continental US or North America but rather expeditionary. For instance, US Central Command in Tampa runs a Command post exercise (CPX) dealing with a country in the Middle East. In this case, the exercise is considered expeditionary despite the fact that the CPX has been held in Tampa.

2.2.2 Joint operational readiness criteria

Whereas the first three criteria correspond to GC direction, the next three criteria provide details on the operational readiness impact of conducting the exercises. As the main goal of the joint exercises to which JETA funds are allocated is to improve the joint operational readiness of the CAF, the criterion Potential to Improve or Enhance Joint Operational Readiness is paramount. Further, these exercises are being conducted with the purpose of preparing the CAF for future operations. Hence, the value of the criterion Relationship to Current and Future Ops was also judged important, but not at the level of the preceding criterion. Finally, the criterion Opportunities for High Readiness Validation was desirable, but rated below the other two criteria, as there are other environmental exercises that are frequently conducted (and paid for by L101 vice JETA funds) that provide opportunities for validation of High Readiness force elements. These operational criteria and their relative rankings were validated by JTA staff.

2.2.2.1 Potential to Improve or Enhance Joint Operational Readiness

This criterion includes five categories: 1) the application of lessons learned based on previous exercise observations; 2) the incorporation of new joint doctrine; 3) the incorporation of new systems, processes and/or technologies; 4) the inclusion or improved use of joint enablers and emerging capabilities; and 5) the achievement of a deeper level of force integration. Using these five categories, the following judgments about the potential of the exercise to improve or enhance joint operational readiness were used:

- **Very significant**: includes all five aspects;
- **Significant**: includes four of the aspects;

- **Moderate**: includes three of the aspects;
- **Limited**: includes two of the aspects;
- **Very Limited**: includes one of the aspects; and
- **None**: includes none of the aspects

2.2.2.2 Relationship to Current and Future Ops

This criterion seeks to determine the relationship of the exercise to current operations, by asking whether the exercise will: replicate a forthcoming operation; replicate a current operation; or not replicate a current operation. Exercises related to forthcoming operations are given more value than those related to current or existing operations. The rationale is that joint training for upcoming operations is the most important in that it represents a new and possibly never-before-executed operation. In this particular case, the GC has authorized the CAF to participate in a specific new mission and has allocated resources towards it. Ranked next are those exercises that are related to operations that the CAF are not currently executing, but may be asked to conduct in the future based on GC policy direction. For example, the Government expects the CAF to be prepared to provide assistance in responding to domestic and international disasters or major emergencies. Therefore, exercises that involve a major disaster scenario would be ranked higher than those exercises that replicate an existing operation. Another example in this category is NATO exercises for an Article 5 scenario. Ranked lowest are those exercises related to operations the CAF are already doing, which presumably do not require additional training (since the CAF is already conducting them) and forces are already being trained for them through mission-specific training.

2.2.2.3 Opportunities for High Readiness Validation

This criterion seeks to determine the potential for an exercise to be a validation opportunity for High Readiness (HR) Force Elements (FEs). Each exercise is to be evaluated on its potential to validate high readiness, using the following three levels:

- **Substantial**: assuredly provides the opportunity to validate the training of multiple HR FEs;
- **Modest**: can possibly provide the opportunity to validate the training of one or more HR FEs;
- **Negligible**: is not expected to provide the opportunity to validate the training of any HR FEs;

2.2.3 Converting criteria scores into value

Each joint exercise's overall value is based on how it scores against the six criteria. First, an exercise's scores are converted into values using linear measurable value functions—one for each criterion [19]. Figure 2 depicts the value, given in brackets, associated with each of the criterion's levels. For example, within GC Interest the Important level is converted into a value of 1, while the Indirect level is converted into a value of 0.33.

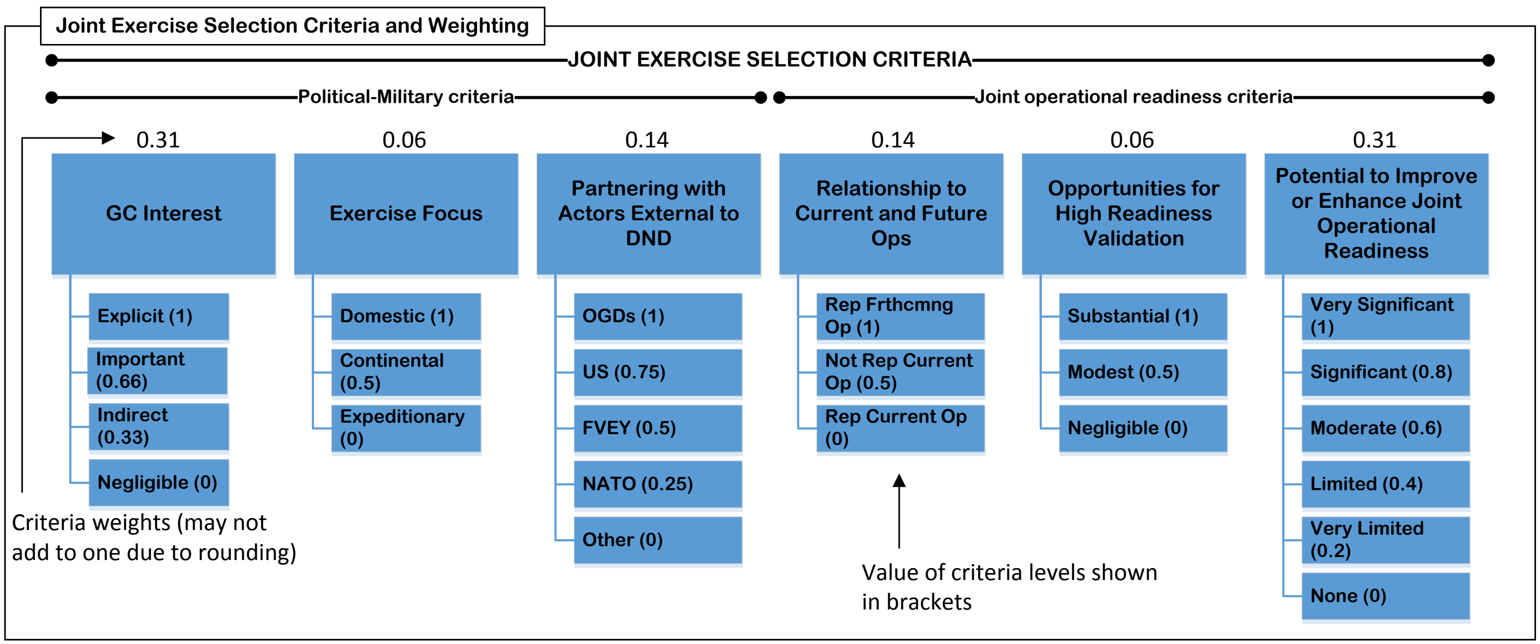


Figure 2: *Value model criteria. The criteria are split into two categories:* Political-Military criteria *and* Joint Operational Readiness criteria. *Each criterion's levels are depicted, and their value (using a linear measurable value function) are given in brackets.*

Next, each exercise's overall value is computed using a measurable value function. There are a variety of approaches to compute a joint exercise's value—e.g., additive, multiplicative, and other non-additive functions [20]. The additive model, which is the most commonly used and is not seen to be overly complicated by decision makers [19, 13], is applicable when the criteria are *mutually preferentially independent*, *difference consistent*, and *difference independent*. As the criteria meet these requirements (e.g., the preference for an exercise with an Explicit score against GC Interest over Important is independent of the remaining criteria, domestic exercises are preferred to continental exercises regardless of the remaining criteria, etc.), an additive linear model was selected. The criteria's weighting, set by decision makers, used in the additive linear measurable value function are described in Section 3.1. The weights must be greater than zero and sum to one. A joint exercise's overall value to the CAF is given as:

$$v_{e,y} = \sum_{i \in \mathcal{C}} \left(w_i \cdot z_{e,y,i} \right), \tag{1}$$

where e is an exercise that exists in the set of candidate joint exercises $\mathcal{E}$, y is the fiscal year in which exercise e first requests JETA funding, i is an index and $\mathcal{C}$ is the set of six criteria, w_i is the weight of the ith criterion, and $z_{e,y,i}$ is the exercise's value associated with the ith criterion.

2.3 Optimization model

Constructing a joint exercise portfolio from a set of candidate joint exercises is a type of combinatorial optimization problem, specifically it may be expressed as a multidimensional knapsack problem [21] or capital budgeting problem [22]. To illustrate, suppose a decision maker considers N candidate investments in each time period of a prescribed planning horizon. Each candidate has a specified cost—which may be incurred over one or more time periods—and a value to the decision maker. In addition, suppose in each time period a budget constraint exists that restricts the inclusion of candidate investments in the portfolio. The objective is then to determine the set of candidate investments that in aggregate provide the maximum value to the decision maker without exceeding the budgetary constraints.

In reality, these types of problems are fraught with uncertainty, including fluctuating investment costs, yields, exchange rates, inflation, etc. While stochastic optimization methods can account for such uncertainties—see, e.g., [23, 24, 25]—within a military context such portfolio decision problems often are first addressed using a deterministic optimization model. This is for a variety of reasons, including: due to a lack of familiarity, a need to demonstrate to military planners the feasibility of optimization methods to tackle such problems [26]; a lack of military planners' willingness to commit to the required stochastic representation of future financial pressures and military requirements [27, 28]; and a tendency of senior planners to use judgment to select a set of representative deterministic scenarios to explore rather than generate them randomly [28]. In fact, a recent survey on the use of portfolio decision analysis in military applications found that methods accounting for uncertainty are not commonly applied [29].

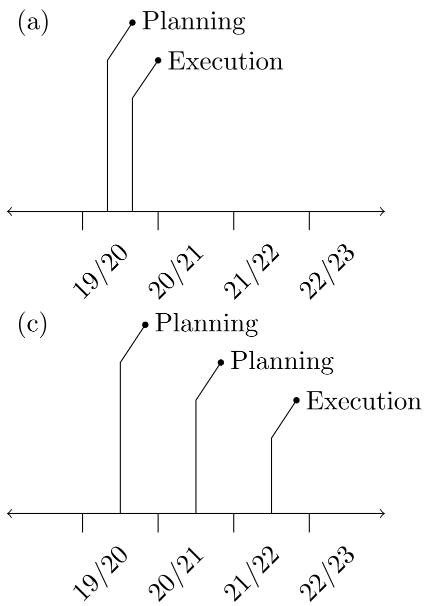


Figure 3: *Example joint exercise activity schedules. (a) Planning and execution of an exercise occur within a single fiscal year. (b) Planning and execution activities of an exercise occur in two consecutive fiscal years. (c) Planning and execution activities of an exercise occur across three consecutive fiscal years. (d) Planning and execution activities of an exercise occur across two consecutive fiscal years.*

Given these reasons, which we found reflected the current state of the JTA staff, we elected to design and implement a deterministic optimization model rather than one that is stochastic. Thus, the realities of uncertain joint exercise costs, fluctuations in partnering due to exogenous events, outcomes of joint task validation opportunities, etc., are not accounted for in the model.

The deterministic optimization model's fundamental aspects are as follows.

(a) **Joint exercises are indivisible and exercise selection is binary.** Joint exercises cannot be subdivided; either an exercise is selected or not selected for inclusion in the portfolio. In addition, each joint exercise can only be selected once.

(b) **Joint exercises typically demand funding over several years.** Each joint exercise consists of two types of activities: *planning* and *execution*. Figure 3 depicts potential joint exercise activity schedules. Each activity has an estimated funding demand—planning activities require JETA funding either within a single fiscal year (as in Figure 3 (a) and (b)) or across two consecutive fiscal years (as in Figure 3 (c) and (d)), and execution activities, which occur upon the completion of planning activities, require JETA funding only within a single fiscal year.

(c) **A joint exercise's value is determined based on six criteria.** The proxy used to measure the value of a joint exercise is based on six criteria (as described in Section 2.2): (1) GC Interest; (2) Exercise Focus; (3) Partnering with Actors External to DND; (4) Relationship to Current and Future ops; (5) Opportunities for High Readiness Validation; and (6) Potential to Improve or Enhance Joint Operational Readiness. An exercise's overall value (see Equation 1) is a computed as a linear weighted sum of its score against each criteria. The criteria's weights used within the computation are set by the decision makers, must be greater than zero, and add up to one.

(d) **The portfolio's value.** The portfolio's value is computed as the sum of the joint exercises' values. The set of joint exercises that maximizes the portfolio's value is thus called the *optimal portfolio*.

(e) **The portfolio is constrained by the available JETA budget.** Within each fiscal year in the prescribed planning horizon, the model restricts the selection of joint exercises such that the sum of their activities' fiscal demands does not exceed the fiscal year's available JETA budget.

(f) **The portfolio, if possible, must provide opportunities to exercise CONPLANs, conduct joint exercises in a variety of geographic regions, and validate tasks withiin the Joint Task List (JTL).** The model accounts for the requirement that all CONPLANs, geographic regions, and joint tasks (for which opportunities exist) must be exercised at a specified frequency. Rather than identifying specific fiscal years in which these opportunities, if possible, must be provided, time-windows of fiscal years are given. Figure 4 depicts time-windows for two CONPLANs in which opportunities are sought. In this example, for CONPLAN A the model may select either Exercise 1, 2, or 3 to meet the requirement for time-window $(A, 20/21)$. It is important to note that the model does not select individual activities, rather it selects exercises. Thus, if the model selected Exercise 1 in the example given in Figure 4, it would allocate JETA funding to both its planning and execution activities.

(g) **Decision maker imposed constraints.** Decision makers may select to force an exercise into or out of a portfolio for various reasons, including: performing what-if analysis, capturing existing decisions that have been made regarding exercise selection, etc. Regardless, decision maker imposed constraints enable a decision maker to assess the opportunity cost associated with a specific decision; that is, the potential loss or gain in terms of how the CONPLAN, joint task, and geographic constraints are addressed.

While these aspects address the problem statement (see the Introduction section), the model excludes certain aspects of building a joint training plan. Specifically, scheduling of exercises is not included due to what is assessed to be extensive data collection requirements of participating units' capacity and availability. In addition, dependence between exercises is also excluded due to that the JTA directed that each exercise should be evaluated and selected on its own merit—that is, the concept of a exercise series does not exist within the model.

The remainder of this subsection may be skipped without loss of continuity. For the interested reader, the model is implemented as an integer programming model and formulated as follows.

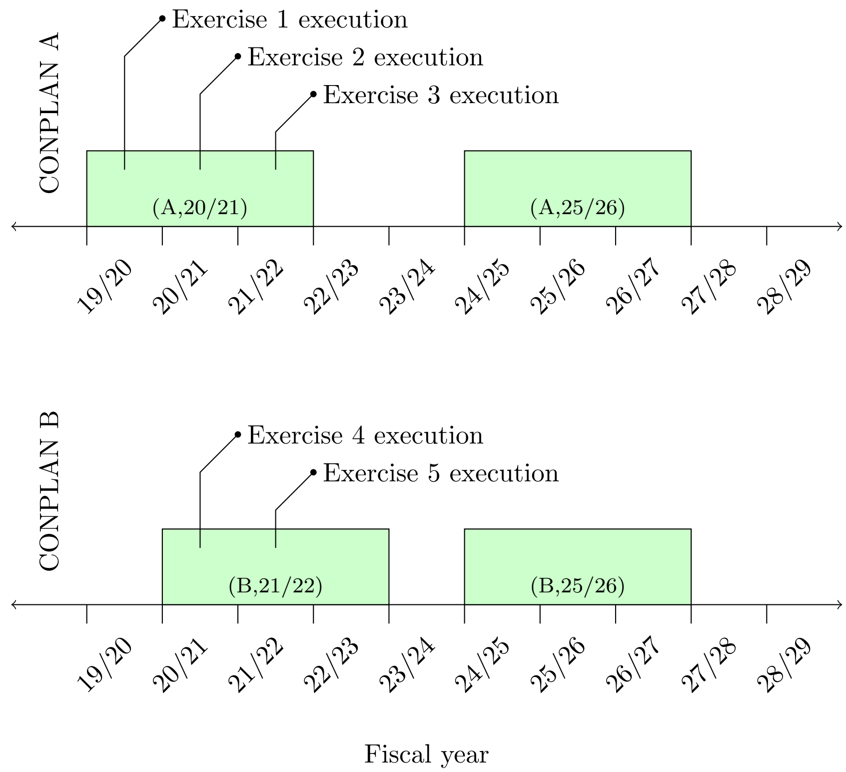


Figure 4: *Example of time-windows for contingency plans. CONPLAN A must be exercised every five fiscal years (2020/21, 25/26, etc.) within a +/- 1 year window. CONPLAN B must be exercised every four fiscal years (2021/22, 25/26, etc.) within a +/- 1 year window. Time-windows are labelled as (CONPLAN, fiscal year), where fiscal year is the centroid fiscal year within the time-window.*

- Equation 2 represents the total value of the portfolio, which is the objective function to be maximized.
- Equation 3 is a financial constraint that ensures that the sum of funds required by the selected joint exercises' activities does not exceed the available JETA budget in each fiscal year considered in the planning horizon.
- Equation 4 ensures that if possible for each CONPLAN at least one candidate joint exercise that exercises the CONPLAN within each of the CONPLAN's time-windows will be selected.
- Equation 5 ensures that if possible for each geographic region at least one candidate joint exercise to be conducted in that region within each of the region's time-windows will be selected.
- Equation 6 ensures that if possible for each task in the JTL at least one candidate joint exercise that provides an oppurtunity to exercise the task within each of the task's time-windows will

be selected.

- Equation 7 ensures the decision to select an exercise is binary.

Objective function:

$$\max_{x} \sum_{(e,y)\in E} v_{e,y} x_{e,y}. \tag{2}$$

Constraints:

$$\sum_{(e,y,y',a)\in C} c_{e,y,y',a} x_{e,y} \leq b_{y'}, \qquad \forall y' \in \mathcal{Y}, \tag{3}$$

$$\sum_{(p,\tau,e,y)\in P} x_{e,y} \geq \delta^{P}_{p,\tau}, \qquad \forall (p,\tau) \in W^{P}, \tag{4}$$

$$\sum_{(g,\tau,e,y)\in G} x_{e,y} \geq \delta^{G}_{g,\tau}, \qquad \forall (g,\tau) \in W^{G}, \tag{5}$$

$$\sum_{(t,\tau,e,y)\in T} x_{e,y} \geq \delta^{T}_{t,\tau}, \qquad \forall (t,\tau) \in W^{T}, \tag{6}$$

$$x_{e,y} \in \{0,1\}, \qquad \forall (e,y) \in E. \tag{7}$$

The sets, parameters, and decision variables are defined as follows.

Sets

$p, \mathcal{P}$	is the index and set of CONPLANs to be exercised;
$e, \mathcal{E}$	is the index and set of candidate joint exercises;
$g, \mathcal{G}$	is the index and set of geographic regions;
$t, \mathcal{T}$	is the index and set of joint tasks within the JTL;
$y, \mathcal{Y}$	is the index and set of fiscal years considered in the planning horizon;
$(e,y), E$	is the pair of joint exercise and fiscal year in which the exercise begins to consume JETA funds;
$(e,y,y',a), C$	is the quadruple of a joint exercise, the first fiscal year in which the exercise consumes JETA funds, a fiscal year ($y' \geq y$), and an activity of the exercise (planning or execution) that requests JETA funds in year y' ($y' \in \mathcal{Y}$);
$(p,\tau), W^{P}$	is the pair of CONPLAN and centroid of a range of fiscal years in which an opportunity is sought, if possible, to validate the CONPLAN ($\tau \in \mathcal{Y}$);
$(g,\tau), W^{G}$	is the pair of geographic region and centroid of a range of fiscal years in which an opportunity is sought, if possible, to have a joint exercise occur within its boundaries ($\tau \in \mathcal{Y}$);
$(t,\tau), W^{T}$	is the pair of joint task and centroid of a range of fiscal years in which a validation opportunity is sought, if possible, to validate the joint task ($\tau \in \mathcal{Y}$);

$(p, \tau, e, y), P$	is the quadruple of CONPLAN, centroid of a range of fiscal years in which an opportunity is sought ($\tau \in \mathcal{Y}$), joint exercise, and fiscal year the exercise begins to consume JETA funds;
$(g, \tau, e, y), G$	is the quadruple of geographic region, centroid of the range of fiscal years in which an occurence opportunity is sought ($\tau \in \mathcal{Y}$), joint exercise, and fiscal year the exercise begins to consume JETA funds;
$(t, \tau, e, y), T$	is the quadruple of joint task, centroid of the range of fiscal years in which a validation opportunity is sought ($\tau \in \mathcal{Y}$), joint exercise, and fiscal year the exercise begins to consume JETA funds;

Parameters

$b_{y'}$	is the available JETA budget in fiscal year y' ($y' \in \mathcal{Y}$);
$v_{e,y}$	is the value (as computed in Equation 1) of candidate joint exercise e that begins consuming JETA funds in fiscal year y;
$c_{e,y,y',a}$	is the cost of activity a that occurs in fiscal year y' for joint exercise e that begins consuming JETA funds in fiscal year y;
$\delta^G_{g,\tau}$	1, 0; 1 if at least one candidate joint exercise e has an execution activity that occurs in geographic region g within a time-window whose centroid fiscal year τ, 0 otherwise;
$\delta^P_{p,\tau}$	1, 0; 1 if at least one candidate joint exercise e has an execution activity that exercises CONPLAN p within a time-window whose centroid fiscal year is τ, 0 otherwise;
$\delta^T_{t,\tau}$	1, 0; 1 if at least one candidate joint exercise e has an execution activity that provides an opportunity to validate joint task t within a time-window whose centroid fiscal year is τ, 0 otherwise.

Decision variables

$x_{e,y}$	1, 0; 1 if candidate joint exercise e that starts consuming JETA funds in year y is selected, 0 otherwise.

In addition, decision maker imposed constraints may be added to the model as follows: $x_{e,y} = 1$ imposes that exercise e beginning to consume funds in year y must be in the portfolio, and $x_{e,y} = 0$ imposes that exercise e begining to consume funds in year y must be out of the portfolio. It should be noted that when a decision maker imposed constraint is added to the model, the optimal portfolio returned by the mathematical programming solver will have a portfolio value less than or equal to the optimal portfolio generated when decision maker constraints are not imposed.

The integer programming model is solved using a branch & bound algorithm [22, p. 271–304] to determine the optimal portfolio.

2.4 Data collection process

Determining the allocation of the JETA fund involves many stakeholders, both within and outside CJOC. This subsection describes how the required data to employ both the value model and optimization model is obtained from these stakeholders, how data inconsistencies are resolved.

From a planning perspective, joint exercises come in two distinct flavours: *CJOC-led* exercises—those planned and executed by the CJOC JTA—and *Level 1 (L1)-led*-–those led by any organization which is *not* CJOC, including L1s such as the Royal Canadian Air Force (RCAF), as well as certain other organizations such as Director General Information Management Operations (DGIMO). The distinction is relevant as the planners for CJOC-led exercises are accessible to and taskable by the JTA, which facilitates timely access to their data and provides for greater control over their content. While the L1s provide data regarding the joint exercises they lead, ultimately the exercises' ratings against the value model's criteria are endorsed by the JTA staff (for the Joint Operational Readiness criteria) and CJOC POLAD (for the Political–Military criteria).

Prior to study's initiation, the primary method through which organizations provided joint exercise data necessary to assess JETA funding requests was the Collective Training and Exercise Schedule (CTES), a database with a web-based interface overseen by the Strategic Joint Staff (SJS). While this database captures a subset of the data required to use the value model and optimization model (e.g., exercise name, requested funding), much of it is not captured. There are medium-term plans to align CTES with the value model and optimization data requirements, but as of this writing they have not come to fruition. As such, in this study joint exercise data was collected via Excel spreadsheets.

Joint exercise data was collected using an iterative approach. First, collection and initial analysis was completed on the CJOC-led exercises in summer 2017 [30]. Based on lessons learned, in winter 2018 the CJOC-led exercise data was refreshed, data regarding new CJOC-led exercises was collected, and data regarding L1-led exercises was collected.[7] While the summer 2017 data set contained multi-year data, for which the optimization model is designed to support, the winter 2018 data set contained only single fiscal year data. This was primarily due to L1 stakeholders not being prepared to provide data beyond Fiscal year (FY) 2018–2019, which proved to be a challenge (discussed in Section 4) when employing the optimization model. In the situation when multi-year data is available, the width of each time-window for the geographic regions, joint tasks, and CONPLANs is ± 1 FY as depicted in Figure 4. However, when only a single year of data exists time-windows are applied with ± 0 FY, as the adjoining years were empty of data, and therefore of opportunities to meet the constraints. While the remainder of this report focuses on the winter 2018 data set rather than the earlier data set, the material presented in Section 4 (Challenges and recommendations) pertains to both.

Two categories of joint exercise data exist: first, data related to the optimization model's constraints (i.e., cost, geographic region, etc.); and second, subject matter expert assessments related to the

[7]This dataset was developed in preparation for informing a potential decision in March 2018 on which exercises would be funded.

optimization model's objective function, and hence the value model criteria (i.e., GC Interest, Relationship to Current and Future Ops, etc.). The former was collected from and validated by exercise planners. The latter was collected from the exercise planners and validated by the JTA staff (for the Joint Operational Readiness criteria) and POLADs (for the Pol-Mil criteria) as follows. During two videoconference sessions in January 2018, each exercise's planner presented an initial assessment of their exercise against the value model's criteria. For the GC Interest criterion, explicit references were required to justify the initial assessment. Next, the JTA staff and POLADs reviewed the ratings, provided feedback to the planners, and determined the final assessments. The validated assessments were then entered into Excel spreadsheets by JTA staff, and subsequently provided to the authors for ingestion into the optimization model. Details on the ingestion process are available in [12].

3 Exploratory analysis and application

This section presents an example application of the methods described in Section 2. First, a description of how the relative importance of the value model's criteria was transformed into numerical weights is presented. Next, an exploratory analysis of the winter 2018 data set is described. Lastly, this section concludes with an example of how the value and optimization models were applied to winter 2018 data set. For technical details of how the models and analysis were implemented see [12].

3.1 Criteria weights

As discussed in Section 2.2, there exists a relative importance between the criteria within the Pol-Mil and Joint Operational Readiness categories. Prior to computing the exercises' values, these importance levels must be transformed into weights. This transformation is performed in a two-step process: first, set the weight of each category's contribution to an exercise's value; and second, set the criteria's weights within each category.

The JTA directed that the two categories equally contribute to an exercise's value [11], and thus it is reasonable to treat each importance level across the categories as equivalent. Table 1 lists the criteria grouped by their importance level. The second step, setting the criteria's weights within each category, is described as follows.[8]

Table 1: *Value model criteria weights. The criteria weight are also shown in Figure 2. Weights have been rounded to two significant figures and do not add to 1.0 due to rounding.*

Criteria			
Pol-Mil	Operational Readiness	Importance	Weight
GC Interest	Potential to Improve or Enhance Joint Operational Readiness	High	0.31
Partnering with Actors External to DND	Relationship to Current and Future Ops	Medium	0.14
Exercise Focus	Opportunities for High Readiness Validation	Low	0.06

It has been well established in the literature (see e.g., [33, 34]) that weights determined by subjective judgment tend to suffer from consistency and validity issues. Poorly chosen weights can unintentionally favour some alternatives over others, so it is preferable to take a more deliberate approach.

One such approach is to identify the least extreme set of weights that satisfy the constraints on their value, or essentially the average of all possible weights. Given the endorsement that each of the two

[8] The establishment of the weights was conducted by a previous member of CJOC OR&A, and informally documented here [31]. This followed closely the approach taken in a previous study [32].

criteria categories will have equal weight, it follows that there are only three unique weights to set: high, medium, and low, which we will refer to as w_H, w_M, and w_L. These values must sum to 0.5, so that the total weight of all six criteria sums to 1.

In a geometric view, the set of possible weights occupies a space defined with the weight values as axes, (w_H, w_M, w_L). The *feasible weight space* [35], is defined by the set of values in that space that satisfy the constraints

$$w_H + w_M + w_L = 0.5, \tag{8}$$

$$w_H \geq w_M \geq w_L \geq 0. \tag{9}$$

The equality constraint in Equation 8 defines a plane in three dimensions. Equation 9 further constrains the possible values on that plane to be positive, and with the high weight being greater than or equal to the medium weight, and the medium weight being greater than or equal to the low weight. The most extreme weights can be found by making each weight as high as possible. The high weight is maximized when the other two are set to 0: ($\frac{1}{2}$,0,0). The medium weight is maximized by holding the low weight at zero, and making it as high as possible without exceeding the high weight: ($\frac{1}{4}$, $\frac{1}{4}$, 0). Finally, the highest the low weight can be is when it is equal to the other two weights: ($\frac{1}{6}$, $\frac{1}{6}$, $\frac{1}{6}$). The centroid of the triangle formed by these points is the average of all the feasible weights. The centroid is located at ($\frac{11}{36}$, $\frac{5}{36}$, $\frac{1}{18}$), or in decimal form the values listed in Table 1. This set of weights was endorsed by the JTA [11].

3.2 Exploratory analysis of the winter 2018 data set

The exploratory analysis that follows covers three areas: the distribution of exercise value and cost, an examination of whether certain exercises uniquely satisfy any of the optimization model constraints, and whether the criteria are satisfactorily independent as to not provide redundant information to the value assessment.

While the initial intent as per the problem statement and the optimization model design was to look at the five-year planning horizon from FY 2019–2023,[9] as described in Section 2.4 stakeholders were not yet prepared to provide complete exercise data[10] beyond FY 2018–2019. The result is that the winter 2018 data set contains exercises for which planning activities exist with no data on the associated execution activities (where those fall in future years as with Figure 3 examples (b) through (d)).[11] Within these limitations, exploratory analysis was employed to identify potential anomalies and outliers, and to enable discussion with the JTA as to whether these were data entry errors or simply reflective of reality. A summary of the winter 2018 data set is presented in Table 2.

[9] As expressed in the full title of the JMRP [9]. More precisely this represents FY 2018–2019 to FY 2022–2023.

[10] In some cases Joint Mission Essential Task (JMET) and/or evaluations against the value model criteria were provided for exercises in future years, but without financial information tied to specific activities that would allow them to be evaluated against the budget constraint.

[11] It should be noted that earlier in the process CJOC provided future year data for exercises with planning activities in FY 2018–2019, but as will be discussed this was not carried through by the other stakeholders.

Table 2: *Overview of the winter 2018 data set (FY 2018–2019), including data related to joint exercises and constraints.*

Data related to joint exercises			Sets related to constraints		
Number of exercises	Number requesting funding	Requested JETA funding ($M)	CONPLANs to be exercised	Regions to include an exercise	Tasks to be validated
107	96	57.6	15	5	45

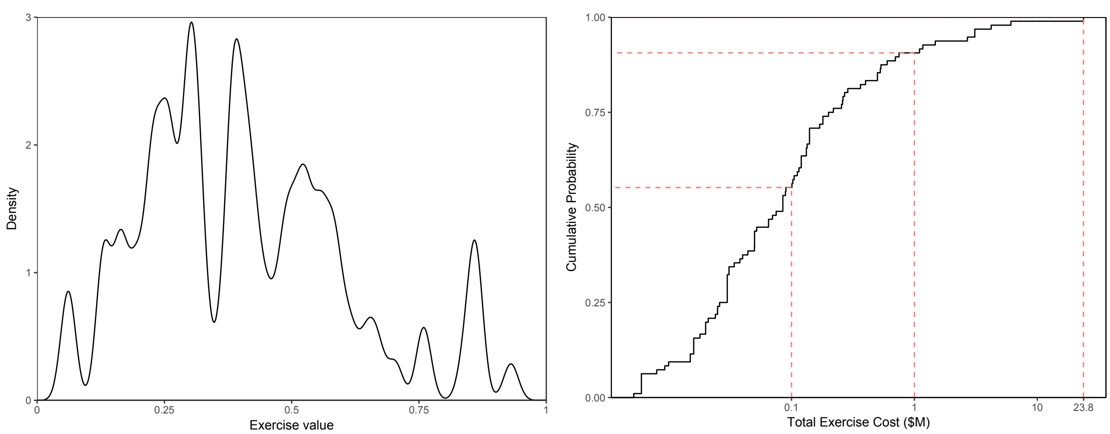


Figure 5: *Distribution of exercise value and cost.* ***Left****: Smoothed density estimate of exercise value in the winter 2018 data set (FY 2018–2019).* ***Right****: Cumulative function of exercise cost for the winter 2018 data set (FY 2018–2019), plotted on log scale. From left to right, dashed red lines indicate: 55 % of exercises are less than $0.1 million, 91 % are less than $1 million, and 100 % less than $23.8 million.*

3.2.1 Exercise value and cost

The distribution of the exercise value is depicted in the left panel of Figure 5.[12] Inspecting the figure reveals a trend with a value less than 0.5, with notable clusters around 0.30 and 0.38; however, a lesser peak exists at the high end of the scale at 0.86.

The cumulative distribution of exercise costs in the winter 2018 data set is presented in the right panel of Figure 5, using a logarithmic scale for the cost to more clearly distinguish the distribution. The dashed red lines indicate from left to right: more than half of the exercises requesting funding are requesting fewer than $\$0.1$ million; more than $90\,\%$ are requesting fewer than $\$1$ million; and all exercises are less than $\$23.8$ million. Thus, the vast majority of exercises are relatively low cost, such as those that involve sending a small contingent of CAF personnel to participate in or observe an international exercise, are executed through table top activities, etc. In contrast, the higher cost exercises tend to involve live exercise in the field. The skew in the cost distribution has practical effects on the decision problem, which will be discussed in sections 3.3 and 4.4.

3.2.2 Examination of the constraints

An analysis of whether the optimization model's constraints can be met by a single exercise, multiple exercises, or not at all provides insight into the composition of the set of candidate exercises, and also the behaviour of the optimization model. Prior to collecting the winter 2018 data set, an analysis of the summer 2017 data set (containing CJOC-led exercises) noted that no exercises occurred in the African region, not all JMETs had an opportunity to be validated, and not all CONPLANs would be exercised [36]. While opportunities were subsequently identified in the African region, this was not the case for the JMETs and CONPLANs, even when the data collection expanded to the L1s. For the JMETs, some cases were due to the creation of new JMETs for which validation opportunities had not yet been planned. For the CONPLANs, it is the case that not all of them are best suited to a joint exercise, but are instead being exercised through L1-specific activities, or simply being regularly used in day-to-day operations. As there can therefore be valid reasons for some elements to not be included in the portfolio, the optimization model was adapted early to not actually require that *all* elements be met, but rather only those where opportunities exist in the provided data (as described in aspect (f) in Section 2.3).

With respect to the winter 2018 data set, Table 3 lists the constraints—two CONPLANs and seven JMETs—that are uniquely met by a single exercise in FY 2018–2019, along with the exercise that meets them. Due to this one-to-one relationship, the exercises listed must be included for a portfolio to be feasible. Three of the JMETs (3.9, 4.5, and 4.6) represent specialist tasks that may only be undertaken in certain situations or by certain units. The remaining four (in the functional group Sustain, with number 5.x) represent advanced logistical tasks that may be expensive to conduct or be difficult to find opportunities to validate.

[12] It is presented as a smoothed histogram, as the nature of the value calculation produces a finite but large number of precise values which do not correspond well with discrete bins.

Table 3: *JMETs and CONPLANs with a single option to be exercised.*

CONPLAN	Exercise
LENTUS	ARCTIC RAM 18
RUBICON	PRECISE RESPONSE 18
JMET	**Exercise**
JT 3.9 Conduct Domestic Chemical, Biological, Radiological Nuclear Operations	TOXIC TRIP 18
JT 4.5 Coordinate Hazard Removal, Survival and Control Measures	MULTINATIONAL MINE COUNTERMEASURES EXERCISE 18
JT 4.6 Manage Information System Security Incidents	RIMPAC 18
JT 5.6 Develop Sustainment Bases	MAPLE FLAG 51 (2018)
JT 5.14 Activate an Operational Support Hub	MAPLE RESOLVE 18
JT 5.15 Deactivate an Operational Support Hub	MAPLE RESOLVE 18
JT 5.17 Theatre Deactivation	MAPLE RESOLVE 18

Table 4: *JMETs and CONPLANs with no options to be exercised.*

CONPLAN	ANGLE CAP Defence of North America LASER NEPTUNE STRIKE NOBLE RECOVERY Plan for the North SUBSAR VIRUS
JMET	JT 1.10 Provide for Historical Documentation JT 3.8 (To be decided) JT 5.11 Plan, Coordinate and Provide Engineer Support Operations JT 5.12 Activate Reserve Forces JT 5.13 Establish an Operational Support Hub JT 5.16 Theatre Activation

Table 4 lists the constraints for which there are no options in the winter 2018 data set. As with the unique opportunities, four of the JMETs that do not have options are in the Sustain group.[13] There is no discernible pattern of which CONPLANs do not have opportunities.

What is perhaps of most concern is that approximately 65 % of exercises have no CONPLAN specified (Figure 8 later in the Section will depict this), particularly when combined with the observation that a number of CONPLANs are not associated with any exercise. While there may be legitimate reasons for this—e.g., Canada having a low amount of influence on a partner's exercise design, or investigating a new area for which formal plans have not been developed—this may also be indicative of either lack of attention to data entry, or sub-optimal exercise design, and should be investigated further.

While this section has summarized what may appear to be limitations in the ability to achieve all of the CAF's joint readiness objectives, it cannot be emphasized enough that the model only considers exercises that are requesting JETA funds, and winter 2018 data set includes exercises within a single fiscal year. These exercises are not the only vehicle for exercising CONPLANs or to validate JMETs,[14] and even these exercises may still be funded from other sources if they are not selected for funding through this process. Exercises that are not joint, training courses, as well as regular operations all also provide important opportunities to accomplish these goals as either a primary or secondary benefit.[15] As such, neither lack of JETA funding for a specific opportunity, nor lack of options drawing on JETA to cover a specific CONPLAN or JMET, automatically implies a capability or readiness gap. Joint exercises make a crucial contribution to joint readiness, but are not the only contribution.

3.2.3 Rating distribution and correlation

When creating a weighted value model with multiple criteria, it is important to consider the potential interdependence or correlation of those criteria. If one or more criteria are highly correlated, they may not truly be measuring different aspects of the underlying phenomenon (in this case, exercises), and consideration should be given as to whether they could usefully be combined to avoid inflating the effect of what is a single underlying aspect.

The correlation between the criteria for all exercises in the winter 2018 data set is presented in Table 5. Spearman's rank correlation coefficient [37] was chosen as it does not require that the underlying data be linearly related, but instead can support comparison between interval or ordinal data because it evaluates only whether there is a potential monotonic relationship between the variables.

[13] JT 3.8 is listed as to be decided, as there is a placeholder in the task list that has not been defined. It is listed for completeness as in the meantime tasks have been defined with higher numbers within the Act function (3.x).

[14] Indeed, in the dataset provided by the JTA staff, there are exercises funded by other sources which cover half of the JMETs with no options in the JETA dataset.

[15] Recall also that joint exercises that replicate current operations are explicitly given a lower value on the relationship to current and future ops criterion, which shows that the JTA recognizes that it is less important to have exercises that are similar to ongoing operations.

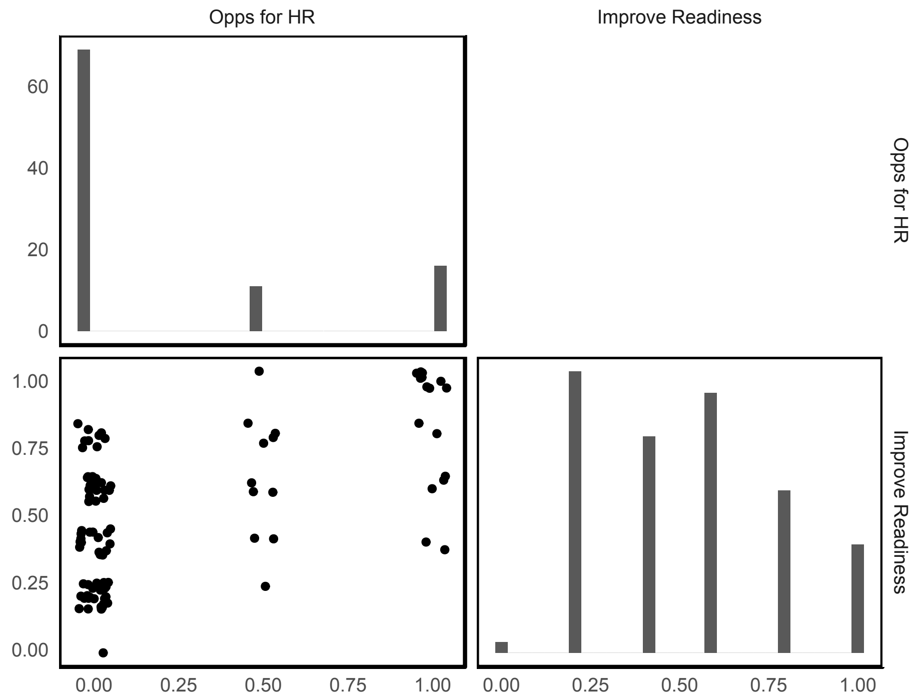
Table 5: Spearman correlations between the criteria. Criteria names have been abbreviated for space. Maximum correlation value has been bolded.

	GC Interest	Exercise Focus	Partnering	Rel to Ops	Opps for HR	Improve Readiness
GC interest	1.00	0.17	0.38	0.06	0.40	0.32
Exercise focus	0.17	1.00	0.44	−0.23	0.23	0.33
Partnering	0.38	0.44	1.00	−0.18	0.24	0.28
Rel to Ops	0.06	−0.23	−0.18	1.00	−0.03	0.09
Opps for HR	0.40	0.23	0.24	−0.03	1.00	**0.53**
Improve Readiness	0.32	0.33	0.28	0.09	0.53	1.00

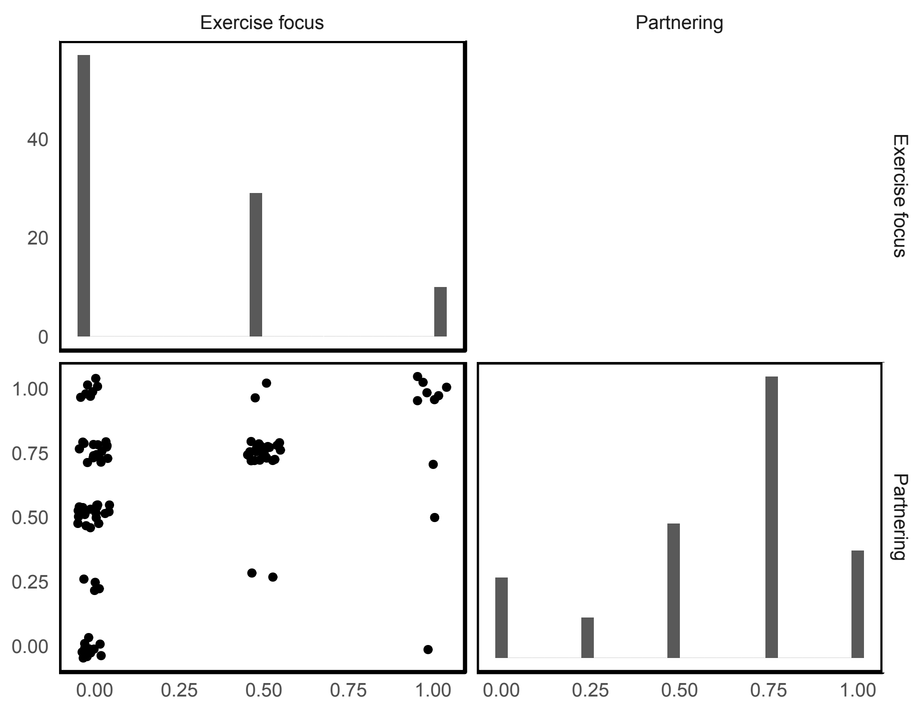
In general, a larger correlation value corresponds to a stronger relationship between two variables, however ultimately the definition of the effect size depends on the context.[16] As a general guide post, Cohen [39] suggests a correlation of 0.5 or greater be used to identify a 'large' effect—this is the criterion used herein. The only inter-criteria correlation that passes this threshold is between Potential to Improve or Enhance Joint Operational Readiness and Opportunities for High Readiness Validation. Recalling that the context here is whether the criteria are providing redundant information to the value calculation, one is equipped to consider whether this particular correlation is problematic.

A plot of underlying data for these two criteria is shown in Figure 6a. The dot plot in the lower lefts shows the joint distribution of each exercises (jitter has been applied to the dots to better display the density). The diagonal row contains plots of the distribution of the individual criterion. The first relevant observation is that over 70 % of the exercises received the lowest of three levels in Opportunities for High Readiness Validation (see upper left panel of Figure 6a), which reduces the potential to identify a true relationship between the values. Conversely, there is only one exercise that received the lowest rating for Potential to Improve or Enhance Joint Operational Readiness (see lower right panel of Figure 6a), although there is a fairly even spread across the other four levels. There is a notable cluster of nine exercises at the highest value for each of the two criteria (in the top right of the lower left panel of Figure 6a); on further inspection, three of those exercises are part of the JOINTEX series, and five are part of the NANOOK series, so a high proportion of the correlation may be coming from splitting up the few highly related exercises into multiple elements, rather than from inherent redundancy in the criteria definitions. Finally, recalling that Opportunities for High Readiness Validation has the lowest weight (0.06, as per Table 1), combined with the low ratings received by most exercises on this criterion, it is not overly affecting the total valuation of exercises. As this correlation affects few exercises in the winter 2018 data set and does not have a large effect on the total exercise value, it is not a cause of concern for the current analysis—although it is worth re-examining as further years of data become available.

[16] This point has been made well in the biological and medical sciences, e.g., "the relationship between cigarette smoking and lung cancer ($r = 0.1$) is considered practically and clinically very important because appropriate legal policy change might save millions of lives. By contrast, the same degree of relationship between cigarette smoking and sleeping hours would not be considered practically or clinically very important; it is hard to imagine that a ban on smoking would happen on the basis of this finding" [38].



***(a)** Opportunities for High Readiness Validation and Potential to Improve or Enhance Joint Operational Readiness*



***(b)** Exercise Focus and Partnering with actors external to DND*

***Figure 6:** Distribution and correlation of specific criteria.*

Although below 0.5, the next highest correlation between Exercise Focus and Partnering with Actors External to DND" should be noted, and is plotted in Figure 6b. Given that higher ratings go to domestic and continental exercises, and higher ratings go to partnering with OGDs and the US, it makes sense that there is some relationship between these ratings. That said, it is clear from the dot plot in the lower left that not every exercise with OGD partners (rating of 1.0) is domestic (rating of 1.0), i.e., there is not a perfect correlation between these two ratings. That said, there is a large cluster of 25 exercises (about a quarter of the total number of exercises) with US partners (rating of 0.75) and a continental focus (rating of 0.5).

3.3 Example application

This section presents an example application of the optimization model, using the winter 2018 data set and a series of notional JETA budget levels. In addition, as part of the iterative approach of this work the optimization model was applied to the summer 2017 data set to study the impact of various proposed JETA budgets for FY 2018–2019. This work is documented in [30] and will not be discussed in detail here, but lessons learned during this previous application will be referred to where relevant.

Given the total request of $\$57.6\,\mathrm{M}$ within the winter 2018 data set, the optimization model was run starting with a relaxed budget constraint of $\$60\,\mathrm{M}$. As had been observed in the earlier work [30] focused only on the CJOC-led exercises, as the budget was dropped by $\$5\,\mathrm{M}$ or even $\$10\,\mathrm{M}$ increments, the optimal portfolio remained unaltered—all exercises with the exception of the most expensive exercise, which is JointEx / Trident Juncture 18 (TJ18), were selected until the budget was reduced to about half of the total request. As JointEx is the CAF's primary training effort, recommending such a portfolio—or doing so without providing alternative courses of action—was not realistic. To enable the example application, a decision maker imposed constraint (as described in Section 2.3) was applied to force the selection of TJ18. The budget was dropped in $\$10\,\mathrm{M}$ increments until infeasibility was reached at $\$30\,\mathrm{M}$. Through a manual binary search an approximate minimum feasible budget of $\$37.5\,\mathrm{M}$ was also located. The resulting portfolios are summarized in Table A.1 in Annex A, with the selected exercises indicated.

A consequence of the design of the objective function (Equation 2) when combined with the distribution of exercises costs (Figure 5) is apparent when comparing which exercises are *not* selected in the $\$50\,\mathrm{M}$ portfolio with a list of the ten most expensive exercises in Table 6. The four exercises that are not selected are all in this list, and another four must be included in any portfolio as they uniquely satisfy constraints (as specified in the right-most columns). The two that remain selected despite not being required by a constraint (NANOOK 18 READY SOTERIA and VIGILANT SHIELD 19) have relatively high value ratings. While NANOOK 18 MARITIME and NANOOK NUNALIVUT have high ratings as well, they are also 3.6–4.1 times more expensive than any other exercise in the data set outside of the top ten. For the objective function to prefer a single exercise with rating 0.86 to selecting four exercises, those four exercises would have to have a *total* value less than that—i.e., an average value of 0.22 or less. However, other than STRIKING VIKING 19, even the most expensive exercises with a rating less than 0.25 have total costs under $\$0.15\,\mathrm{M}$. In general, for data sets with such structure the model will tend not to select high cost exercises unless they are constrained in—such as with the a manual constraint added to require the inclusion of TJ18 in these portfolios—or provide an opportunity to validate a CONPLAN, joint task, or conduct an exercise in a geographic regions that is not provided by other exercises. This issue will be explored in more detail in the Section 4.

***Table 6:** The ten most expensive exercises in the data set, with a) those selected in the $50 M portfolio indicated by a *; and b) the constraints forcing the inclusion of the exercise indicated where applicable. Note that CONPLANs constraints are not listed as none are met.*

				Constraint met	
Exercise	Total cost ($ M)	$50 M	Value	JMET	Imposed
TJ18	23.8	*	0.704		*
RIMPAC 18	6.10	*	0.555	JT 4.6	
MAPLE RESOLVE 18	4.21	*	0.541	JT 5.14, 5.15, 5.17	
NANOOK 18 Maritime	3.10		0.861		
NANOOK 18 READY SOTERIA	3.10	*	0.931		
NANOOK NUNALIVUT	2.70		0.861		
MAPLE FLAG 51 (2018)	1.48	*	0.315	JT 5.6	
VIGILANT SHIELD 19	1.17	*	0.840		
CHUMEX 19	1.10		0.254		
STRIKING VIKING 19	0.750		0.193		

Figures 7 through 9 depict the coverage of regions, CONPLANs and JMETs for each portfolio.[17] Each plot has a cut line at one, representing that at least one exercise must be included in each of the categories where possible. As described in Section 3.2.2, there are several JMETs and CONPLANs where only one option is available, so the constraint is tight even at the highest budget level.

The heavy emphasis on the Americas evident in Figure 7 aligns with the priority order emphasis on domestic, continental, and expeditionary operations in Canada's Defence Policy [18] (see also Section 2.2.1.3). The coverage of CONPLANs as depicted in Figure 8 is also uneven. LENTUS and RUBICON are only covered by one exercise each, which as noted above guarantees the inclusion of the associated exercises in any feasible portfolio. The many exercises with no CONPLAN specified that remain included even in the lowest budget scenario indicates that these likely are needed to meet JMET or geographical constraints, or are so inexpensive as to be within the margin of rounding.[18] Also of note is that JUPITER is the most commonly specified CONPLAN; based on feedback on the earlier analysis [30], this may point to a need for further granularity on which aspects of what is a fairly extensive plan are actually being exercised in each case.[19]

Lastly we consider the coverage of the JMETs, as depicted in Figure 9. Overall, it can be seen

[17]Note that these plots only include exercises with execution phases in this fiscal year, as the optimization model requires an execution phase to occur to consider that a constraint has been met.

[18]Recalling that more than half of exercises are requesting less than $0.1 million, lowering the budget to $37.49 million or $37.48 million could cause additional exercises to be excluded, but in a realistic budgeting scenario amounts this low would likely be managed.

[19]More specifically, while TJ18 was noted to not uniquely exercise any CONPLAN, the JTA staff expressed the opinion that it was the only exercise that explored some of the command and control constructs within JUPITER.

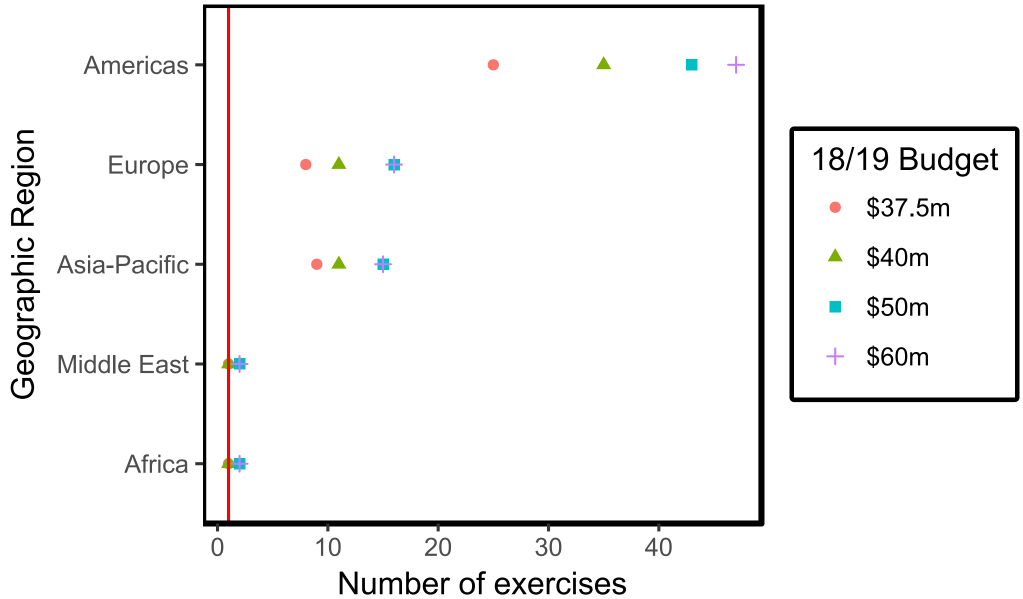


Figure 7: *Plot of regional coverage in portfolios generated for four different hypothetical JETA funding levels for FY* 2018–2019.

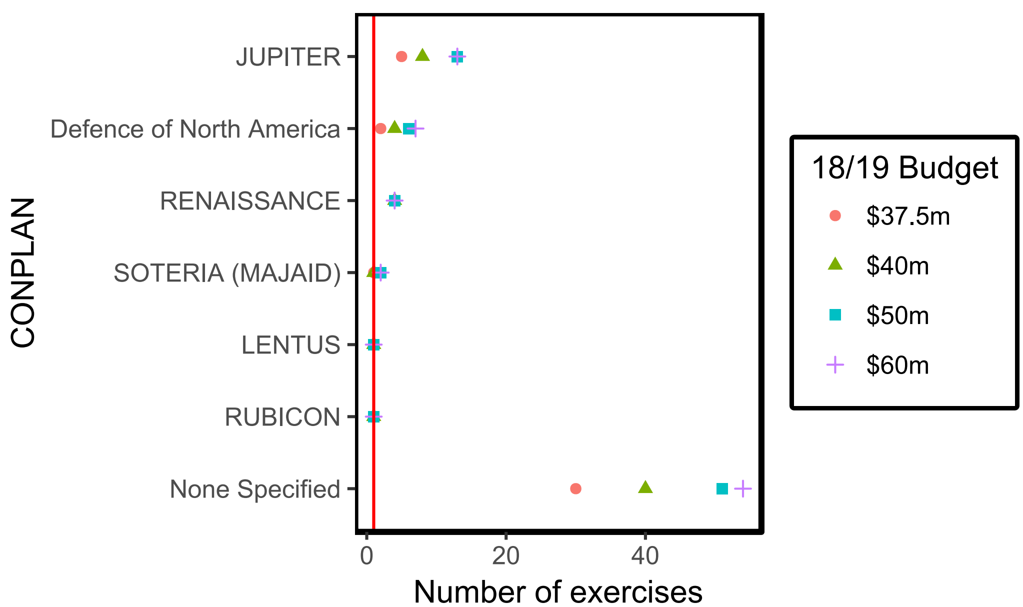


Figure 8: *Plot of CONPLAN exercise opportunities in portfolios generated for four different hypothetical JETA funding levels for FY* 2018–2019.

that most of the tasks have many opportunities to be validated. When viewing them by function, it can be observed that there are a relatively high number of opportunities within the Command (JT 1.x) and Sense (JT 2.x) operational functions (top two panels of Figure 9); this is perhaps not surprising, as any military operation or exercise necessarily involves a command element, and sensing is also nearly a prerequisite. Overall there is a trend that the tasks that have a higher series number within their function have fewer opportunities for validation, which may reflect the order in which they have been added—planners may not have had time to absorb and respond to the very newest functions, and the most primordial tasks were likely added to the lists first. Overall, given the wide variety and high number of JMETs compared to the CONPLANs and regions, the task constraints may have a much larger influence on ensuring the inclusion of a wide variety of exercises in the portfolio (although a single exercise may cover 40 or more tasks).

3.4 Summary of results

This section described the setting of the criteria weights, an exploratory analysis of the winter 2018 data set, and an example application of the optimization model and an analysis of its output. While the analysis presented did not directly support JETA budget decision in FY 2018–2019, it revealed several characteristics of the candidate joint exercises' data and optimization model. These will be explored more fully in the following section.

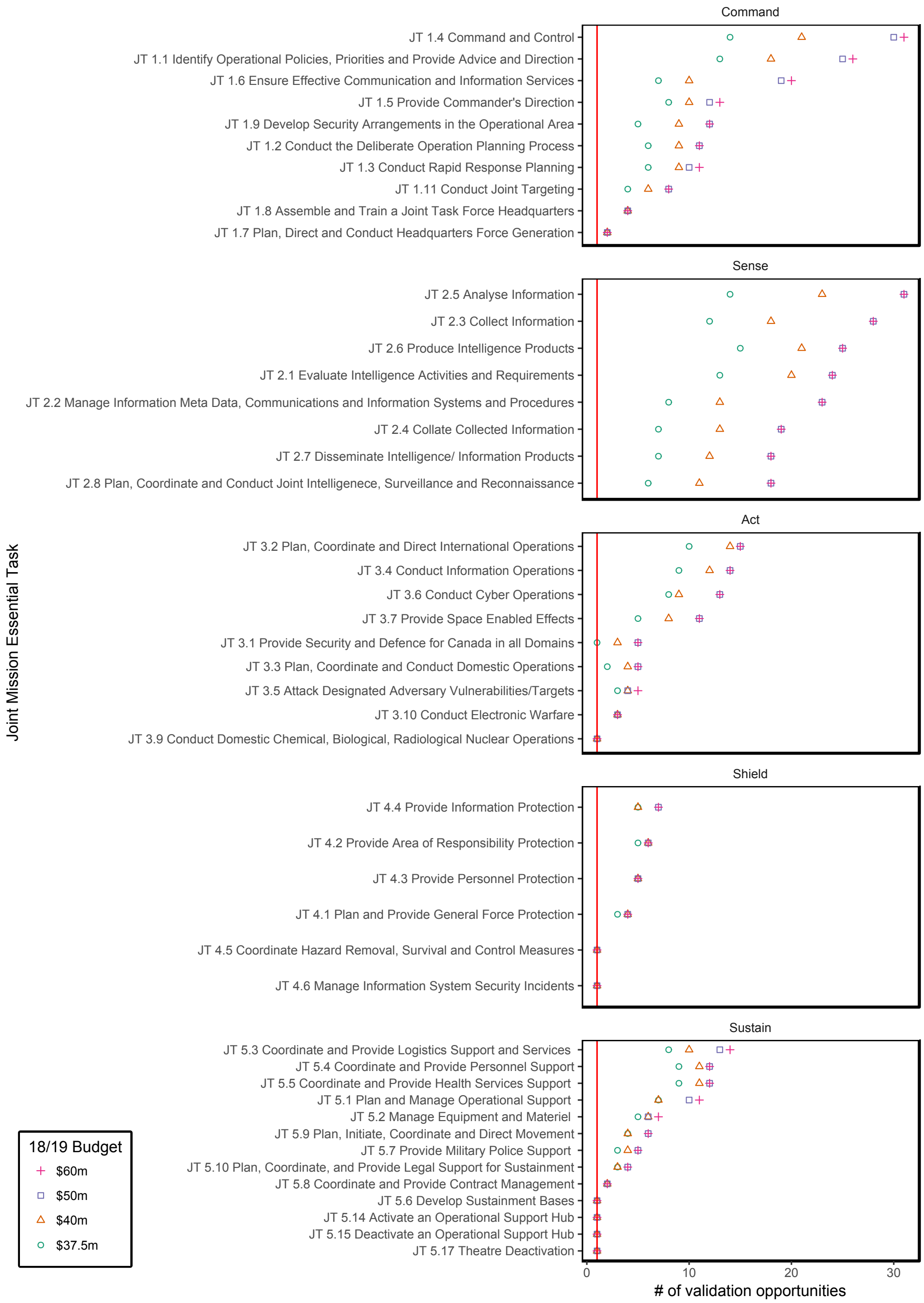


Figure 9: *Plot of JMET validation opportunities in portfolios generated for four different hypothetical JETA funding levels for FY* 2018–2019*, sub-divided by operational function. The red line at one indicates that one exercise must be included for each JMET for which an option is available.*

4 Challenges and recommendations

This section discusses challenges with employing the existing value and optimization models and provides recommendations aimed at enhancing the decision support provided to the JETA business planning process. The recommendations comprise short-term mitigation strategies as well as longer term solutions.

4.1 Multi-year planning data

As stated in Section 1, this study's objective was to provide a means of selecting a set of joint exercises to be conducted over 'a given period', which through consultations with JTA staff was determined to be the five-year planning horizon of the JMRP [9]. However, collected exercise data has been limited to three fiscal years when focusing on CJOC-led exercises [30] and one year when considering both CJOC and L1-led exercises (see Section 3). Such limited data is a major obstacle whose impact is threefold: (1) an inability to generate a full five-year joint exercise plan; (2) the optimization model can not account for constraints being met in other years when *building a portfolio*, although it is designed into the model; and (3) as a result the assessment of the *impact of today's decisions* is incomplete. While the first impact is perhaps obvious, the second and third will be explained further below.

Building an exercise portfolio: When using exercise data from only a single fiscal year, the logic of the optimization model is subtly altered from the multi-year case. In either case, exercises in the data set with execution activities are selected such that the JMET, geographic region, and CONPLAN constraints are met. Once the constraints are met, as the budget increases, exercises that are not necessary to meet constraints are added to increase the portfolio's value. The issue with this step in a single-year scenario is that exercises with only planning activities tend to have a smaller budget request, so will be preferentially selected over exercises with an execution activity. This pattern arises due to that with a single year's worth of data it is assumed that all constraints must be met within the given fiscal year; that is, the time windows' centroids (see Figure 4) are set to be the given fiscal year, and thus there is no temporal flexibility when meeting the constraints. In contrast, when multi-year data is available, the time windows' centroids may vary and the optimization model is able to consider exercises with activities spread across multiple fiscal years (see Figure 3) to meet the JMET, geographic region, and CONPLAN constraints. Most importantly, any planning activity will have an associated execution activity in some fiscal year, and the cost of that execution activity must be balanced against that year's budget constraint when selecting the complete exercise. That said, even when multi-year data is used, ultimately the final fiscal year will be unavoidably subject to this same issue.

Impact of today's decisions: It is difficult to assess the impact of the optimization model's recommended funding decisions when exercise data across the full planning horizon is not accessible. First, selecting exercises within a limited planning horizon may lead to unplanned redundancy in the portfolio in terms of JMETs, geographic regions, and CONPLANs. The result is that the balance of joint exercises within the portfolio may be sub-optimal when viewed from a long-term planning perspective. Second, for those selected exercises with only planning activities in the planning horizon's latter years, it is difficult to ascertain if the cost of their execution activities will fit within the future JETA budgets due to the budgets being uncertain, unknown costs of the execution activities, and unknown costs of other exercises yet to be considered. Thus, while the resulting portfolio may appear to be feasible, these *end effects* [27] make it difficult to make such an assessment.

> **Recommendation #1**: It is advised that the JTA emphasize the value of collecting multi-year planning data to both CJOC-led and L1-led exercise planners. Such data would make better use of the optimization model's ability to track constraints and activities across a multi-year planning horizon, thus allowing a more deliberate and informed joint exercise portfolio development process. In addition, to account for the end effects, the data collection should be extended past the end of the planning horizon to ensure that the execution activities of those joint exercises with planning activities in the planning horizon's latter years are considered.

4.2 Tracking of past data

Due to the time window concept, tasks validated, CONPLANs exercised, and geographic regions in which exercises occurred in FYs prior to the planning horizon do not necessarily need to be repeated in the short term—exercise selection is influenced by the joint exercise program's recent history. The optimization model accounts for this information through allowing specification of the time windows' centroids. To date it has been assumed that the centroid of first time window for each JMET, CONPLAN, and geographic region is the first FY in the planning horizon. This is due to several factors: (1) while previous JMRPs document the planned exercise program, these have not been converted into a machine readable form; (2) not all of the elements of the joint exercises that were planned may have been executed, or may not have met their objectives;[20] (3) some exercises may have been cancelled entirely due to unforeseen events; and (4) not all of the exercises may even have been executed yet, as the current fiscal year is still in progress when planning for the next begins.

> **Recommendation #2**: To support the optimization model's ability to generate exercise portfolios that are fit for purpose, the JTA is encouraged to explore approaches to capture both exercise plans and outcomes such that they are in a machine readable format. In addition, CJOC OR&A should explore how such information may be used to set the time-windows centroids, and to assess the potential to not fund an execution activity whose planning activity was funded (potentially with some penalty function added to the objective to discourage this).
>
> he optimization model may be modified to more explicitly incorporate the meeting of constraints by previously executed exercises, and to allow for the potential to not fund an execution activity whose planning activity was funded (potentially with some penalty function

[20]For instance, a JMET may have been unsuccessfully validated, a CONPLAN may not have been effectively exercised, etc.

added to the objective to discourage this).

4.3 Tracking of exogenous data

The constraints related to JMETs, CONPLANs, and geographic regions are not only informed by recently executed exercises, but also CAF activities such as force generation, mission-specific training, and operations. Such activities may not only influence the time windows' centroids, but may also eliminate a subset of the constraints, e.g., frequent force employment activities may eliminate the need to validate a specific JMET. However, to date the optimization model has not accounted for such exogenous activities; rather, it assumes that all constraints must be addressed using JETA funds.[21]

Recommendation #3: In coordination with both CJOC-led and L1-led exercise planners, it is advised that the JTA track and review activities that may influence the requirements to validate joint tasks, exercise CONPLANs, or conduct exercises in specific geographic regions. Such tracking and review may occur at the annual Joint Training Advisory Group Conference and/or the bi-monthly Joint Training Advisory Group teleconference. In addition, it is advised that CJOC OR&A modify the optimization model to more explicitly incorporate the meeting of constraints by exogenous activities.

4.4 Inclusion of expensive exercises

As depicted in Figure 5, exercise costs for FY 2018–2019 span three orders of magnitude from roughly $10 k to over $20 M.[22] Exercise values, however, only span a single order of magnitude, from approximately 0.06 to 0.93, as depicted in Figure 5. As a result, an exercise that is 50 times more expensive than another cannot be 50 times more valuable, which makes it unlikely for more expensive exercises to be included on a value for money basis; rather, they are most likely to be included where they uniquely meet constraints, as discussed in Section 3.3.

The extreme disparity in costs brings to mind the rocks, pebbles, and sand metaphor that is commonly used in business management [40, 41].[23] When briefing the earlier CJOC-led only results

[21] While this may result in some overplanning or redundancy, the JTA may not have control or even influence over whether some of these activities happen. In the absence of certainty—or at least a representation of uncertainty—it is prudent to continue to plan joint training as if these other activities will not happen. Where there is certainty, the decision maker can advise that it is acceptable that certain constraints not be met by the JETA-funded program.

[22] An important caveat here is that TJ18 is notionally being run on a cycle where only every third year is it run as an expeditionary exercise, so it is more expensive than it would be in the other two years of the cycle. Further, RIMPAC is only run every two years, so the two most expensive exercises in the current data set only occur together in this form every six years. This warrants some caution in drawing firm conclusions from what is likely an outlier year.

[23] While the earliest examples seem to be applied to time management and prioritizing within life or work, it is also applied to resources investments. Specifically, it states that when considering investments, rocks—those that are most important—should be considered first, followed by the less important pebbles and sand, as trying to add rocks into a jar after it is already filled with pebbles and sand is not possible, while the converse is.

[30], JTA staff expressed concern that what they saw as a big rock (TJ18) was not being included in portfolios by the optimization model without manual intervention, a situation which carried through to the example application in Section 3.3. The view was expressed that there was a certain inherent value to conducting longer and larger live exercises (which come at considerable expense), and that this was not being properly reflected in the value and/or optimization model. The most expensive exercises in the current data set have relatively high, but not the highest, value ratings (see Table 6), which can mean either (a) size is not being adequately reflected in the value model; or (b) some less expensive exercises may genuinely be as big or bigger rocks (i.e., highest *value*, rather than size) as the largest exercises.

Recommendation #4: In the near term, it is recommended that decision maker imposed constraints continue to be used to ensure expensive exercises which are deemed as rocks are included in the portfolio—this sort of manual intervention in algorithmically generated recommendations is consistent with recent research on increasing acceptance of the results of optimization models [42], and makes the decision maker conscious of expressing their true preferences. In the longer term, the following adjustments to the models could be investigated by CJOC OR&A to potentially reduce the need for decision maker imposed constraints: (a) CJOC OR&A investigate the impact of using non-linear measurable value functions to convert an exercise's scores to value, thus given significantly greater value to those with higher scores;[24] (b) investigate adding one or more new constraint(s) that explicitly represent the preference for including TJ18 or a similar exercise in a more generic way (e.g., a 'main training effort' or 'expeditionary major combat scenario' constraint)[25]; (c) in collaboration, JTA and CJOC OR&A explore how the number of training person-days per exercise in combination with a constraint on the minimum number of training person-days could affect the inclusion of exercises within the portfolio; (d) in collaboration, JTA and CJOC OR&A investigate approaches to categorize each exercise as a rock, pebble, or sand (e.g., large, medium, and small) and subsequently modify the optimization model to employ tiered exercise selection approach as described in [43].

4.5 Scheduling conflicts

Beyond those constraints included in the existing optimization model, other constraints exist which impact a joint exercise portfolio's feasibility. For instance, the selected exercises' schedules may be such that they are in competition for resources, including General / Flag Officers, military staff from same unit, tactical airlift, etc. In these situations, what may be reported as a feasible portfolio by the optimization model, may in reality be infeasible due to what would be the simultaneous request of resources.

[24] Noting that given the scores in Table 6, this would emphasize the selection of some of the moderately expensive exercises in the NANOOK series, rather than TJ18, so may not address the decision makers' concern.

[25] For the latter it may be particularly important to have multi-year data to consider meeting this over a window, rather than per year.

Recommendation #5: In the near term, where the JTA staff can identify a resource conflict, it is recommended that a decision maker imposed constraint be added to the model to prevent the inclusion of both of the conflicting exercises. In the longer term, it is recommend that in collaboration, JTA and CJOC OR&A investigate whether it is feasible to collect data on resources that may come into conflict, and represent this information and associated constraints directly in the optimization model.

4.6 Uncertainty

As discussed in Section 2.3, building a joint exercise portfolio is fraught with uncertainty, including whether JMETs are validated, the JETA budget, and so forth. In particular, throughout the data collection process three types of uncertainty were observed: exercise costs, both epistemic (number of personnel, location, etc.) and aleatory (exchange rate, inflation, etc.); epistemic uncertainty in the exercises' assessments against the value model's criteria; and epistemic uncertainty in their ability to meet constraints.[26] While the existing deterministic optimization model may be used to address JETA budget uncertainty through building portfolios for various budgets and comparing the results, it cannot account for uncertain exercise costs or assessments.

Recommendation #6: As an effort to acknowledge and begin to account for uncertainty within the JETA business planning process, it is advised that (a) the JTA collect each exercise's (i) minimum, maximum, and most likely cost for each of its planning and execution activities, and (ii) minimum and maximum assessments against each value model criterion; (b) CJOC OR&A, in collaboration with JTA, (i) design a chance constraint [44, pp. 124–134] to be included within the optimization model, i.e., the portfolio's cost will not exceed the available JETA budget with a given probability, and (ii) modify the optimization model to account for the uncertain exercise assessments and ability to meet constraints, such as maximizing the portfolio's expected value [45, pp. 62–76], minimizing probability of not meeting the constraints [46], etc.

[26] For instance, it may be uncertain which partners will participate in a future exercise, or the full list of which JMETs may be possible to validate.

5 Conclusion

This scientific report describes the application of strategic analysis and operational research to address how the CAF can get the most value from its joint training funds. This work's primary contributions are twofold. First, a value model, designed using a strategy-to-task approach, that consists of a set of criteria to objectively assess the value of a joint exercise to the CAF. Second, an optimization model whose objective is to build a balanced portfolio of joint exercises which best reflect government policy and force posture direction, subject to the constraints required of the JTA. The models were used to provide decision support on a set of CJOC-led exercises in summer 2017 [30], as well as on a set of joint exercises including both CJOC-led and L1-led in winter 2018 as described in Section 3. Taken together, these methods greatly enhance the JTA's ability to develop and refine a joint exercise training program. As such, the approach described herein has been institutionalized as of April 2018 to be part of the JTA's joint readiness planning process, the JMRP [8, 9].

While the models have reached initial operating capability, several challenges, discussed in Section 4, exist to fully realize the intent of the problem statement. Most pressing is the collection of multi-year planning data for joint exercises, as this is vital to employing the value model and optimization model to build a five-year joint exercise program. To do so, the JTA must emphasize the significance of multi-year planning data to all exercise planners. Related is the tracking and collecting of exercise plans and outcomes from the current and prior years in a machine readable format, which is key to ensuring that portfolios generated through the optimization model are not unnecessarily redundant in terms of geographic regions, JMETs, and CONPLANs. Although addressing these challenges may be difficult, the data will go a long way to improving the decision support provided to the JTA.

With respect to the recommendations that involve refinement to the optimization model, the near-term solutions for recommendations 4 and 5 both involve the setting of decision maker imposed constraints, and moving forward recommendations 2 and 3 may require the setting or overriding of elements of the optimization model at a relatively low level. Opportunities exist to exploit extant Defence Research and Development Canada (DRDC) initiatives to facilitate this, including ongoing efforts to generalize existing portfolio decision-support models [43] to create a generic interactive framework for the integration of optimization models and visualization tools for multiple problems. Beyond DRDC, integrating the models with DND's defence program analytics initiative would enable better linkages with other data sources within the Department.

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Annex A Example portfolios

This annex lists the portfolios generated for the example application in Section 3.3. Table A.1 lists those joint exercises from the winter 2018 data set included (indicated by a *) and not included in four different portfolios, each with a different JETA budget constraint.

Table A.1: *Exercises included in portfolios with different JETA budgets.*

	Budget ($M)			
Exercise Name	37.5	40	50	60
AFRICAN LION 18		*	*	*
AMALGAM DART 18-02		*	*	*
AMALGAM DART 19-01	*	*	*	*
ARCTIC CARE 18	*	*	*	*
ARCTIC CARE 19	*	*	*	*
ARCTIC RAM 18	*	*	*	*
ARCTIC ZEPHYR 18	*	*	*	*
ARDENT DEFENDER 18	*	*	*	*
ARDENT YAHALOM 18	*	*	*	*
ARRCADE GLOBE 18	*	*	*	*
ATLANTIC SERPENT 18	*	*	*	*
BOLD QUEST 18			*	*
BULLSEYE 18		*	*	*
CHUMEX 19				*
COALITION VIRTUAL FLAG 18-4		*	*	*
COBRA GOLD 18	*	*	*	*
COORDINATED RESPONSE 19	*	*	*	*
CRISIS MANAGEMENT EXERCISE 19	*	*	*	*
CYBER COALITION 18	*	*	*	*
CYBER FLAG 18			*	*
CYBER GUARD 18	*	*	*	*
CYBER WARRIOR 18		*	*	*
CYBER X 18	*	*	*	*
DEPLOYED MISSION SUPPORT CENTRE 18		*	*	*
DRAGON WARRIOR 18 (Fall)	*	*	*	*
DRAGON WARRIOR 18 (Summer)	*	*	*	*
DRAGON WARRIOR 19 (Spring)	*	*	*	*
DYNAMIC MANTA 19			*	*
DYNAMIC MONGOOSE 18			*	*
EAGER LION 18	*	*	*	*
EQUATEUR 19	*	*	*	*
FAC - CCA 18	*	*	*	*
GLOBAL MEDIC 18-01		*	*	*
GLOBAL MEDIC 18-02	*	*	*	*
GLOBAL SENTINEL 18	*	*	*	*
GLOBAL THUNDER 18	*	*	*	*
INTERDICT 18	*	*	*	*
INTERNAL LOOK 18			*	*
ITX 18		*	*	*
JOINT WARRIOR 18-1			*	*
JOINT WARRIOR 19-1			*	*
JOINTEX 18.2 / TRIDENT JUNCTURE 18	*	*	*	*

Exercise Name	Budget ($M) 37.5	40	50	60
JOINTEX 19			*	*
JOINTEX 19.1 JOINT OPERATIONS SYMPOSIUM	*	*	*	*
KEY RESOLVE 18		*	*	*
KEY RESOLVE 19			*	*
LOCKED SHIELD 18	*	*	*	*
MAGNUM NIGHT 19	*	*	*	*
MAPLE FLAG 51 (2018)	*	*	*	*
MAPLE RESOLVE 18	*	*	*	*
MAPLE STRIKE 18-01	*	*	*	*
MULTINATIONAL MINE COUNTERMEASURES EXERCISE 18	*	*	*	*
NAMSI GOMEX 18	*	*	*	*
NAMSI GOMEX 19		*	*	*
NANOOK 18 Maritime				*
NANOOK 18 READY SOTERIA			*	*
NANOOK 18 Whole of Government			*	*
NANOOK NUNAKPUT 18		*	*	*
NANOOK NUNALIVUT				*
PACIFIC PARTNERSHIP 18	*	*	*	*
PANTHER STRIKE 18	*	*	*	*
PANTHER STRIKE 19	*	*	*	*
PAPA TERRA 18	*	*	*	*
PHOENIX EXPRESS 19		*	*	*
PRECISE RESPONSE 18	*	*	*	*
QUICKSHOT 18 (Fall)	*	*	*	*
QUICKSHOT 18 (Summer)	*	*	*	*
RED FLAG NELLIS 18	*	*	*	*
RIMPAC 18	*	*	*	*
RIMPAC 20	*	*	*	*
SOUTHERN KATIPO 19	*	*	*	*
STEADFAST COBALT 18			*	*
STEADFAST COBALT 19		*	*	*
STEADFAST INTEREST 18		*	*	*
STORM FORCE 18		*	*	*
STRIKING VIKING 19				*
TEMPEST EXPRESS 33	*	*	*	*
TEMPEST EXPRESS 34	*	*	*	*
TEMPEST EXPRESS 35	*	*	*	*
TOXIC TRIP 18	*	*	*	*
TRADEWINDS 18			*	*
TRADEWINDS 19		*	*	*
TRIDENT MERMAID 18	*	*	*	*
TRUMAN COMPUTEX 18		*	*	*
ULCHI FREEDOM GUARDIAN 18			*	*
UNIFIED FOCUS 19	*		*	*
UNIFIED RESOLVE 19			*	*
UNITAS AMPHIBIOUS 18		*	*	*
UNITED ACCORD 18		*	*	*
UNITED ACCORD 19			*	*
VIGILANT PACIFIC 18			*	*
VIGILANT SHIELD 19			*	*
VIGILANT SHIELD 19 (RCAF)			*	*

	Budget ($M)			
Exercise Name	37.5	40	50	60
VIGOROUS WARRIOR 19	*	*	*	*
WESTERN PACIFIC NAVAL SYMPOSIUM 18			*	*
WILD BOAR 18		*	*	*

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List of symbols, abbreviations, and initialisms

ASEAN	Association of Southeast Asian Nations
CAF	Canadian Armed Forces
CDS	Chief of the Defence Staff
CJOC	Canadian Joint Operations Command
CONPLAN	Contigency plan
CPX	Command post exercise
CTES	Collective Training and Exercise Schedule
DGIMO	Director General Information Management Operations
DND	Department of National Defence
DRDC	Defence Research and Development Canada
FE	Force Element
FVEY	Five Eyes
FY	Fiscal year
GC	Government of Canada
HR	High Readiness
JTA	Joint Training Authority
JETA	Joint Exercise Training Allocation
JMET	Joint Mission Essential Task
JMRP	Joint Managed Readiness Program
JTL	Joint Task List
FP&R	Force Posture and Readiness
L1	Level 1
MND	Minister of National Defence
MINA	Minister of Global Affairs Canada
NATO	North Atlantic Treaty Organization

NORAD	North American Aerospace Defence Command
OGD	Other Government Department or Agency
OR&A	Operational Research and Analysis
PM	Prime Minister
POLAD	Policy Advisor
Pol–Mil	Political–Military
RCAF	Royal Canadian Air Force
SJS	Strategic Joint Staff
SSE	Strong, Secure, Engaged
TJ18	JointEx / Trident Juncture 18
UK	United Kingdom
UN	United Nations
US	United States

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Joint exercises are vital to the Canadian Armed Forces (CAF) meeting their readiness targets. However, CAF resources are often insufficient to participate in all candidate joint exercises, which posed a research question: *how can the CAF get the most value out of its joint training resources?* Using strategic analysis and operations research, we designed a value model to gauge a joint exercise's value and an optimization model to support decision makers when selecting a joint exercise portfolio. This scientific report describes these models, presents an example of their application, discusses challenges encountered with their application, and provides recommendations aimed at overcoming them.

Les exercices interarmées sont essentiels pour que les Forces armées canadiennes (FAC) puissent atteindre leurs objectifs de préparation opérationnelle. Toutefois, les ressources des FAC sont souvent insuffisantes pour participer à tous les exercices interarmées proposés, ce qui a mené à une question de recherche : Comment les FAC peuvent-elles profiter au maximum de leurs ressources d'entraînement? Au moyen d'une analyse stratégique et d'une recherche sur les opérations, nous avons conçu un modèle de valeur pour juger de la valeur d'un exercice interarmées, et un modèle d'optimisation pour appuyer les décideurs au moment de sélectionner le portefeuille d'un exercice interarmées. Le rapport scientifique décrit ces modèles, présente un exemple de l'application, discute des difficultés vécues dans l'application, et fournit des recommandations pour surmonter ces difficultés.