# On a Second Generation Strategic Decision-Making Process for the Canadian Forces


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## ABSTRACT

*In 2005, the Canadian Forces' (CF) Chief of Defence Staff announced the commencement of the transformation of the CF. As with any complex organization, transformation of its structure and processes is not simple. However, the success of such a transition "depends upon leadership first identifying and understanding the thematic components of the past, and then, learning how to adapt and exploit the thematic strengths 'today' for the benefit of 'tomorrow'" [1]. While several themes have been identified within the CF transformation, a theme in which the analytical community plays a vital role is strategic decision-making. Strategic decision-making, in the context of defence acquisitions, has traditionally been a reactive process [2]. In an effort to migrate defence acquisitions towards a proactive process, a rational forward-looking decision-making process has been developed: the Force Development (FD) process. At the core of this process is Capability Based Planning (CBP), whose analytical process and associated tools provide decision-makers with an objective assessment of capability deficiencies, adequacies, and affluences. This objective assessment is central to the following defence acquisition trade-off analysis, whose output is a cost-effective strategic capability roadmap.*

*The FD process and first generation CBP analytical process have been recently reported [3][4][5][6]. Development of the second generation CBP analytical process has now been completed, which focused on advancement of the process and tools. In this paper a brief summary of the FD process is presented. This is followed by an overview of the second generation CBP analytical process, including a description of its methods with an emphasis on how they work together and their advancements since the first generation. This is followed by a discussion of the proposed next-generation CBP analytical process and tools. Key implementation challenges are highlighted.*


## 1.0 INTRODUCTION

### 1.1 Background

In 2005, the Canadian Forces' (CF) Chief of Defence Staff announced the commencement of the transformation of the CF. As with any complex organization, transformation of its structure and processes is not simple. However, success of such a transition "depends upon leadership first identifying and understanding the thematic components of the past, and then, learning how to adapt and exploit the thematic strengths 'today' for the benefit of 'tomorrow' " [1]. Several themes have been identified, such as civil-military relations, individualism, and strategic decision-making. Strategic decision-making, particularly in the context of defence acquisitions, is a theme in which the operational research community plays a vital role.

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14. ABSTRACT

**In 2005, the Canadian Forces (CF) Chief of Defence Staff announced the commencement of the transformation of the CF. As with any complex organization, transformation of its structure and processes is not simple. However, the success of such a transition depends upon leadership first identifying and understanding the thematic components of the past, and then, learning how to adapt and exploit the thematic strengths today for the benefit of tomorrow [1]. While several themes have been identified within the CF transformation, a theme in which the analytical community plays a vital role is strategic decision-making. Strategic decision-making, in the context of defence acquisitions, has traditionally been a reactive process [2]. In an effort to migrate defence acquisitions towards a proactive process, a rational forward-looking decision-making process has been developed: the Force Development (FD) process. At the core of this process is Capability Based Planning (CBP), whose analytical process and associated tools provide decision-makers with an objective assessment of capability deficiencies, adequacies, and affluences. This objective assessment is central to the following defence acquisition trade-off analysis, whose output is a cost-effective strategic capability roadmap. The FD process and first generation CBP analytical process have been recently reported [3][4][5][6]. Development of the second generation CBP analytical process has now been completed, which focused on advancement of the process and tools. In this paper a brief summary of the FD process is presented. This is followed by an overview of the second generation CBP analytical process, including a description of its methods with an emphasis on how they work together and their advancements since the first generation. This is followed by a discussion of the proposed next-generation CBP analytical process and tools. Key implementation challenges are highlighted.**

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Strategic decision-making for defence acquisitions has traditionally been a reactive process; that is, basing equipment acquisitions on capabilities[1] that have been vital or unsatisfactory during previous CF missions [2]. This approach was previously sufficient, however is now deemed inadequate for various reasons, such as the diversity of military operations (e.g., domestic and continental operations, reacting to a major terrorist attack, supporting civilian authorities) [7] and the importance of strong financial management practices (i.e., the Department of National Defence (DND) may only carry forward surplus funds equivalent to 1% of its yearly budget) [8]. In response, the Department has migrated its strategic decision-making process for defence acquisitions from a reactive one to a rational forward-looking process: the Force Development (FD) process. At its core is Capability Based Planning (CBP) [9], which consists of two components: ‘future security analysis’ and ‘capability planning, management, and integration’. The output of the ‘future security analysis’ component is a set of force planning scenarios that describe the future security environment, while the ‘capability planning, management, and integration’ component, which is implemented by an analytical process (i.e., set of operational research methods) known as the CBP analytical process, uses the force planning scenarios to produce an objective assessment of the Department’s defence capability deficiencies, adequacies, and affluences. This objective assessment is central to the following defence acquisition trade-off analysis, whose output is a cost-effective strategic capability roadmap (SCR). The SCR is a key element in the transformation of strategic decision-making in the CF.

## 1.2 Objective

The objective of this paper is to provide an overview of the second generation CBP analytical process[2], discuss its methods and how they compare to the first generation methods, and briefly present an introduction to the proposed next generation of the CBP analytical process. For a complete description of the first generation CBP analytical process, including its methods, the reader is referred to previous papers by Blakeney *et. al.* [3][4], Taylor *et. al.* [5], and Christopher *et. al.* [6].

## 1.3 Scope

CBP exists within the larger FD process, which in turn exists in conjunction with the CF/DND strategic decision-making governance structure. While it is important to be cognisant of the governance structure (i.e., the results of CBP process are utilized throughout the governance structure), shown in Figure 1, it will not be discussed in this paper. For further information on the structure, the reader is referred to the Capability Based Planning Handbook [2].

## 1.4 Outline

The remainder of this paper is organized as follows: Section 2 presents an overview of the FD process, which is presented to provide a context for the CBP analytical process; Section 3 presents an overview of the second generation CBP analytical process and its methods, and highlights modifications of each method since the first generation; Section 4 briefly presents an introduction to the proposed next generation of the CBP analytical process; and Section 5 presents a conclusion.

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[1] A capability may be defined as “A particular ability that contributes to the production of a desired effect in a given environment within a specified time and the sustainment of that effect for a designated period. Capability is delivered by an appropriate combination of PRICIE components.” [2]. PRICIE refers to the functional components of a capability: Personnel/Leadership/Individual training, Research and Development/Operational Research, Infrastructure, Environment and Organization, Concepts, Doctrine, Collective Training, Information Management & Technology & Equipment Support.

[2] It should be noted that the first generation CBP analytical process was known as the SCR analytical framework. The name has been changed to emphasize the process rather than the output.

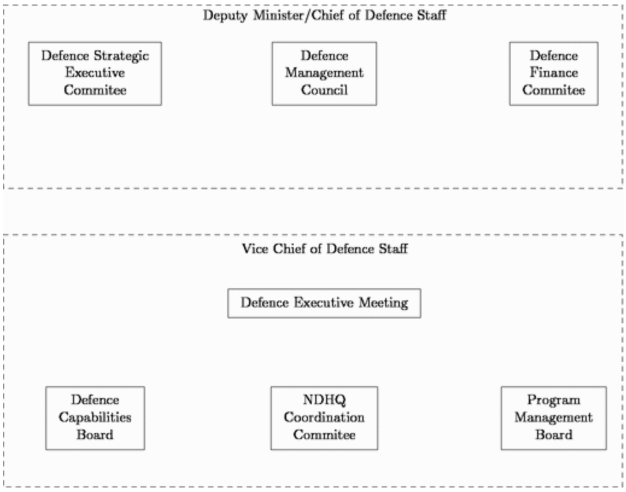


**Figure 1: CF/DND Strategic Decision-Making Governance Structure. The lower four boards/committees are chaired by the Vice Chief of Defence Staff and the upper three committee/councils are chaired by the Deputy Minister and Chief of Defence Staff.**

## 2.0 FORCE DEVELOPMENT PROCESS

The strategic decision-making process for defence acquisitions is a key process within any modern defence enterprise. The CF, in an effort to migrate its process towards a proactive one, has designed and implemented an end-to-end process that uses government strategic guidance as its input and as its output generates employable force elements[3] for the CF operational commands: the Force Development process. The FD process[4] is shown in Figure 2. While several feedback mechanisms exist within the process, two key loops are those between the 'Capability Based Planning' and 'Strategic Guidance' components and the 'Key Products' and 'Capability Based Planning' components. It should be noted that the SCR, which is envisioned as a key element for transformation of strategic decision-making within the CF, exists within the 'Key Products' segment and is a direct output of the 'Capability Based Planning' component.

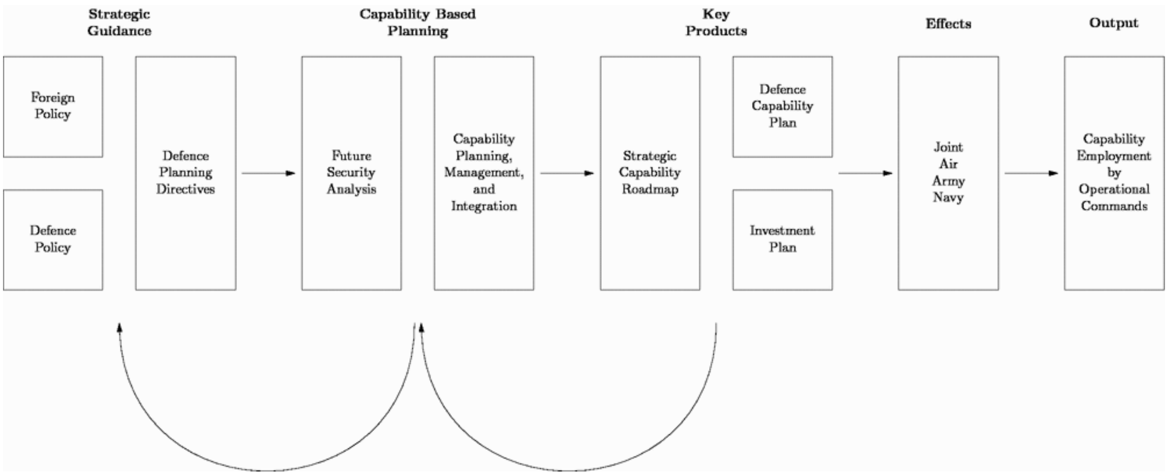


**Figure 2: CF Force Development Process**

[3] A force element is defined as a fundamental unit within the CF that can be utilized to provide capability within an operation. The unit may perform a tactical, operational, or strategic level function [6]. Examples of force element are one C-17 (i.e., strategic lift), one fixed-wing search and rescue aircraft, and an engineer field squadron.

[4] The CF FD process is a waterfall model (i.e., sequential development process) with feedback.

The FD process begins with an assessment of strategic guidance, such as foreign and defence policy, (e.g., Canada First Defence Strategy [7]), and defence directives from senior military and civilian leadership. This guidance, which describes current and future defence and security priorities, forms the input to the CBP component.

The CBP component is split into two segments: 'future security analysis' and 'capability planning, management, and integration'. The 'future security analysis' segment evaluates the future security environment and generates force planning scenarios[5] that represent operations the CF is likely to be engaged in given the strategic guidance. In conjunction with the force planning scenarios, there exists a capability framework that describes the full spectrum of military capabilities that the CF either has, may have in the future, or neither but are required by the scenarios. The framework, which provides a common language to discuss CF capabilities, is a hierarchical structure where each level of the structure provides a greater degree of fidelity (i.e., an element in level 1 of the structure may be divided into three elements in level 2, and each may be further divided in level 3). The force planning scenarios and capability framework form the input to the 'capability planning, management, and integration' component.

The 'capability planning, management, and integration', which is the analytical engine of CBP, is further divided into three elements: 'capability planning', 'capability management', and 'capability integration'. The 'capability planning' component identifies the capability framework elements[6] that the force planning scenarios require. This process begins with an evaluation of six standardized effects[7] within each scenario: control, shape, stabilize, shield, project and sustain, and informed direction. Each effect is evaluated by assessing its required frequency and the consequence to the success of the scenario if the effect is not created. Subsequently, each capability framework element is evaluated against each effect through assessing its required frequency and the consequence to the success of each scenario if the element is not able to create the effect. These evaluations are translated into numerical scores[8], for example as described by Billyard and Blakeney [10]. Along with the numerical scores, a set of questions, known as measures of capability, are created for each capability framework element. The purpose of the measures of capability is to further quantify and qualify the role of the capability framework elements within the scenario.

The 'capability management' component, which is the follow-on process to 'capability planning', determines how the CF will provide the aforementioned capability framework elements within each scenario. The process begins through comparing the capability framework element requirements with existing and programmed operational force elements over time for each scenario and subsequently assigning force elements to framework elements. The scenarios' force element requirements are combined together to form concurrent scenario force element requirements. This information is summarized in two interim results, a capability outlook and a risk outlook. The capability outlook provides a high-level view of the potential of the existing and programmed operational force elements to achieve individual scenario capability framework element requirements over time. The risk outlook provides a view of the operational risk to the success of a scenario, and combinations of scenarios (i.e., concurrent scenarios). These two interim outputs provide the basis for the determination of the set of CF capability deficiencies, which are those capability framework elements that do not have adequate force elements assigned.

[5] The force planning scenarios depict a range of domestic, continental, and international events and possibilities across the full spectrum of conflict [2].

[6] A level within the capability framework (e.g., level 4) is selected to perform the assessment.

[7] An effect is defined as a physical, functional, or psychological outcome, event, or consequence that results from the execution of specific tasks [2].

[8] The numerical scores may be used to create a prioritized list of capabilities for each scenario.

While the capability and risk outlooks aid the understanding of the capability deficiencies, they do not provide insight into how to address the deficiencies. This is performed in the 'capability integration' component through a three step procedure: determination of capability alternatives to address each deficiency; selection of a set of alternatives; and review/approval of selected alternatives by decision-makers. It should be noted that the set of deficiencies generally vary over the time, and therefore the three step procedure must be repeated for each time period of interest. While any time period may be used for further analysis, only the deficiencies that exist in the final time period studied are considered. The set of approved alternatives for this set of deficiencies are one of the key inputs to the SCR .

The key products of the FD process are: SCR, investment plan, and the defence plan. The SCR, which is the direct output of the CBP component, is the aforementioned list of approved alternatives as well as government approved initiatives (e.g., Canada First Defence Strategy [7]). The alternatives are ranked based on a variety of metrics, such as cost, military value, and personnel requirements. As well, each alternative and government initiative is mapped to a set of tangible projects. These projects, along with a proposed implementation schedule, form the input to the investment plan. The final key product, the defence plan, is a business plan that provides defence tasks and resource allocation. It is primarily a management tool that integrates priorities, vision, and policy.

The key products described above articulate the capability deficiencies of the CF and how to address them; however, they are not the final output of the FD process. The measurable effects, which are those created by the Joint, Army, Navy, and Air Force, as well as the generated employable force elements are final outputs. It is these that determine the success, or failure, of the process as a whole.

The feed forward path (i.e., 'strategic guidance' → 'capability based planning' → ...) is the primary path in the FD process; however, the feedback paths play an important as well. The role of the feedback paths is to provide the ability to apply corrective action (e.g., modifying strategic guidance, removal of a capability deficiency) within the FD process. For example, the feedback path between 'capability based planning' and 'strategic guidance' recognizes that the capability based planning process may influence the strategic direction provided by the government. As well, the feedback path between the 'key products' and 'capability based planning' recognizes that the investment plan is not static, due to changing project timelines and funding, and subsequently impacts the selection of alternatives to address capability deficiencies. While these feedback mechanisms do not play as a significant role as the feed forward path, they do contribute to the maintenance of the SCR and investment plan.

## 3.0 CAPABILITY BASED PLANNING ANALYTICAL PROCESS

The core of the FD process, as described in the previous section, is CBP. The CBP component, which is further divided into 'future security analysis' and 'capability planning, management, and integration', transforms its inputs (i.e.., foreign policy, defence policy) into a strategic capability roadmap through applying soft[9] (e.g., subjective analysis of effects and capability framework elements in scenarios) and hard (e.g., optimization of alternatives to address capability deficiencies) operational research techniques. The 'capability planning, management, and integration' component is the analytical engine of CBP, and is implemented through the CBP analytical process. The second generation CBP analytical process is based on its predecessor [3][4][5][6], which in turn is based on the generic process proposed by The Technical Cooperation Program Joint Systems and Analysis Group Technical Panel 3 [14]. While similar to previous work, the second generation introduces new methods and modifications to existing methods.

### 3.1 Overview

The CBP analytical process is comprised of a set of soft and hard operational research methods that collectively implement the second component of CBP, which is 'capability planning, management, and

[9] For further information on soft operational research methods in defence problems the reader is referred to Heyer [16].

integration'. The process, shown in Figure 3, is segmented into three sections: 'capability planning', 'capability management', and 'capability integration', similar as to the division of the CBP 'capability planning, management, and integration' component described in the previous section. The process is comprised of inputs, analytical methods, subject matter expert analysis, and outputs that are represented by bevelled boxes, rectangles with headers, rectangles, and rounded rectangles respectively. There are five analytical methods (i.e., CATCAM, $SC_2RAT$, Concurrency, Optimization, and Cost Sensitivity) and two subject matter expert analyses (i.e., risk outlook and alternative to project mapping). The remainder of Section 3 provides an overview of each analytical method, including their inputs, outputs, and modifications since the previous generation. The risk outlook is discussed in the Concurrency section and alternative to project mapping is discussed in the Cost Sensitivity section.

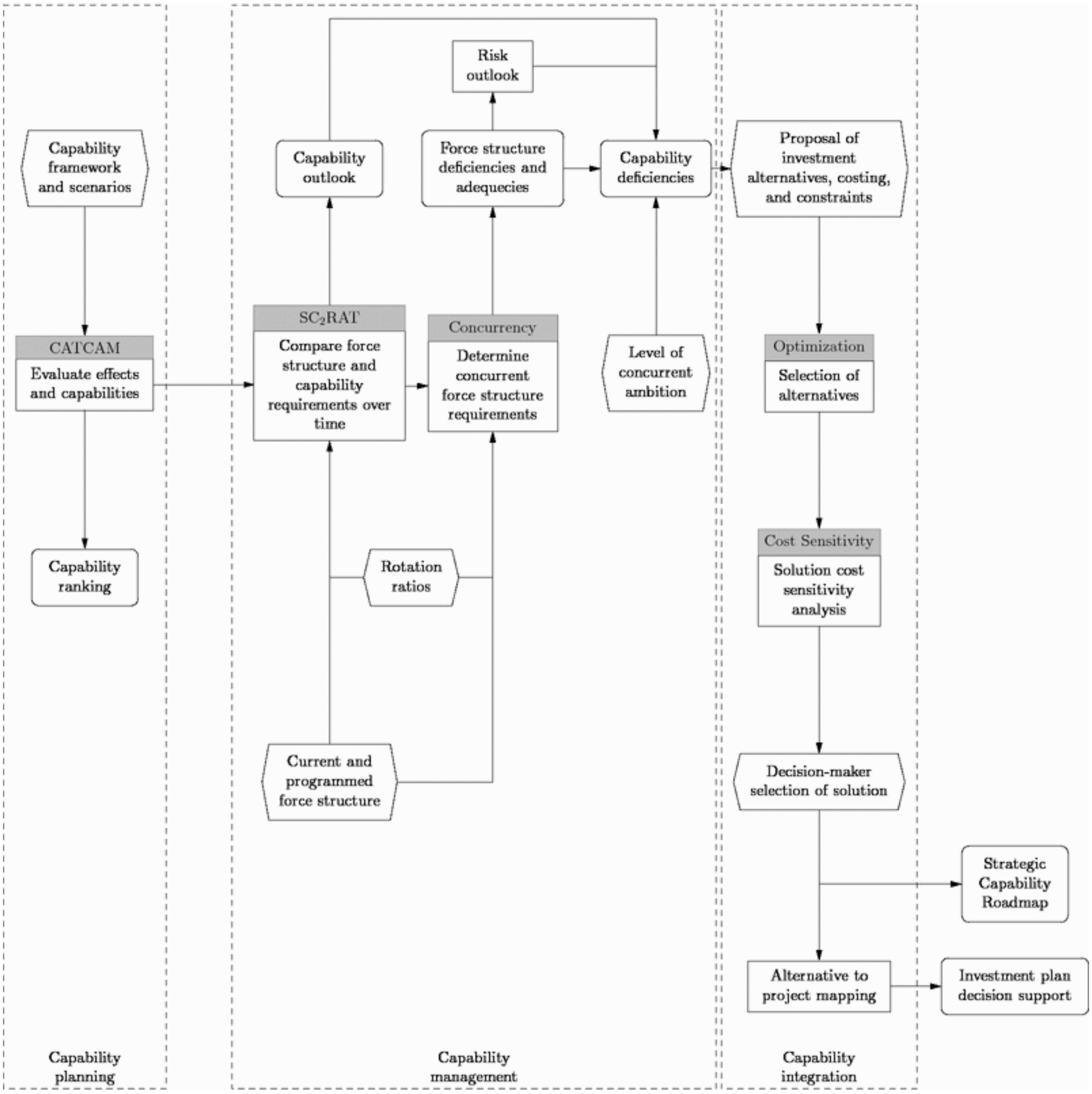


**Figure 3: Second Generation CBP Analytical Process. Inputs are represented by bevelled boxes, analytical methods are represented by rectangles with headers, subject matter expert analyses are represented by rectangles, and outputs are represented by rounded rectangles.**

## 3.2 CATCAM

CATCAM [10][11][12], that is the Chief of Defence Staff Action Team 3 Capability Assessment Methodology, is a key operational research tool in the CBP analytical process. Its primary purpose is to evaluate and prioritize the capability framework elements[6] within force planning scenarios. This is accomplished through subject matter experts assessing each of six standardized mission effects with respect to their required frequency and the consequence if the effect is not created within each scenario. Subsequently, subject matter experts assess the capability framework elements that are required to create the effects through the elements' required frequency and the consequence if the elements can not create the effects[10]. For example, Figure 4 shows a segment of the CATCAM method in which the 'Control' effect is assessed to have a high frequency and high consequence and the 'Deny Portions of the Sea' framework element is assessed to have a low frequency and medium consequence with respect to the 'Control' effect for the given scenario. The assessments are converted into numerical scores, and an overall score for each capability framework element across the effects is calculated using a weighted sum[11] based on normalized mission effects scores [10]. These scores may then used to prioritize the capability framework elements within each scenario. The set of numerical scores for each scenario is passed between the 'capability planning' and 'capability management' components. As well, a set of questions, known as measures of capability, are provided with each assessment. The purpose of the measures of capability is to further quantify and qualify the role of the capability framework elements throughout the scenarios.

| | | | Effect | Effect | Effect |
|---|---|---|---|---|---|
| | | | Control | Shape | Stabilize |
| **Capability** | **Functions** | **Activities** | hh | hm | ml |
| Maritime Effects Production | Deny Maritime battlespace to OPFOR | Defeat OPFOR Maritime Platforms | mh | mm | |
| | | Deny Portions of the Sea | lm | ll | |
| | Provide freedom of manoeuvre in Maritime battlespace | Combine forces for operations | | | hh |
| | | Control Sea Lines of Communication | mm | mh | |
| | | Defeat or avoid OPFOR Maritime mines | ll | lm | |
| | | Control Merchant shipping | | | mm |
| | | Conduct coastal security | | ll | |

**Figure 4: Example segment of CATCAM with sample data [4].**

The algorithms within the second generation CATCAM tool are similar to those employed in the first generation; however, modifications were made to accommodate for an extended capability framework. Whereas the first generation capability framework consisted of four levels (i.e., Domain → Capability → Function → Activity), the second generation capability framework included a fifth level (i.e., Subactivity)

[10] It should be noted that the capability framework elements can be labelled as 'enablers'; that is, they do not deliver an effect themselves, rather they enable other framework elements to deliver an effect [12].

[11] It should be noted that the calculation assumes that the effects are orthogonal; that is the evaluation of one effect does not influence the evaluation of a second effect.

in order to provide a greater degree of fidelity throughout the CBP analytical process. An example of a segment of the second generation capability framework is shown in Figure 5. In order to accommodate the fifth capability framework level, and allow a comparison with first generation results (i.e., the Activity level of the capability framework was assessed in the first generation), the capability framework element assessments were performed in two stages. The elements within the Activity level were evaluated in an identical manner as to those in the first generation. However, the elements in the Subactivity level were evaluated with respect to their associated Activity level elements rather than the effects (i.e., the frequency with which the Subactivity is required to perform the Activity and the consequence the Activity can not be performed if the Subactivity can not be performed). The Subactivity scores were computed in a similar manner as to the Activity scores, however rather than being weighted by the effects they were weighted by their associated Activity. Thus, the 'capability planning' component of the CBP analytical process passed Activity and Subactivity scores to the 'capability management' component.

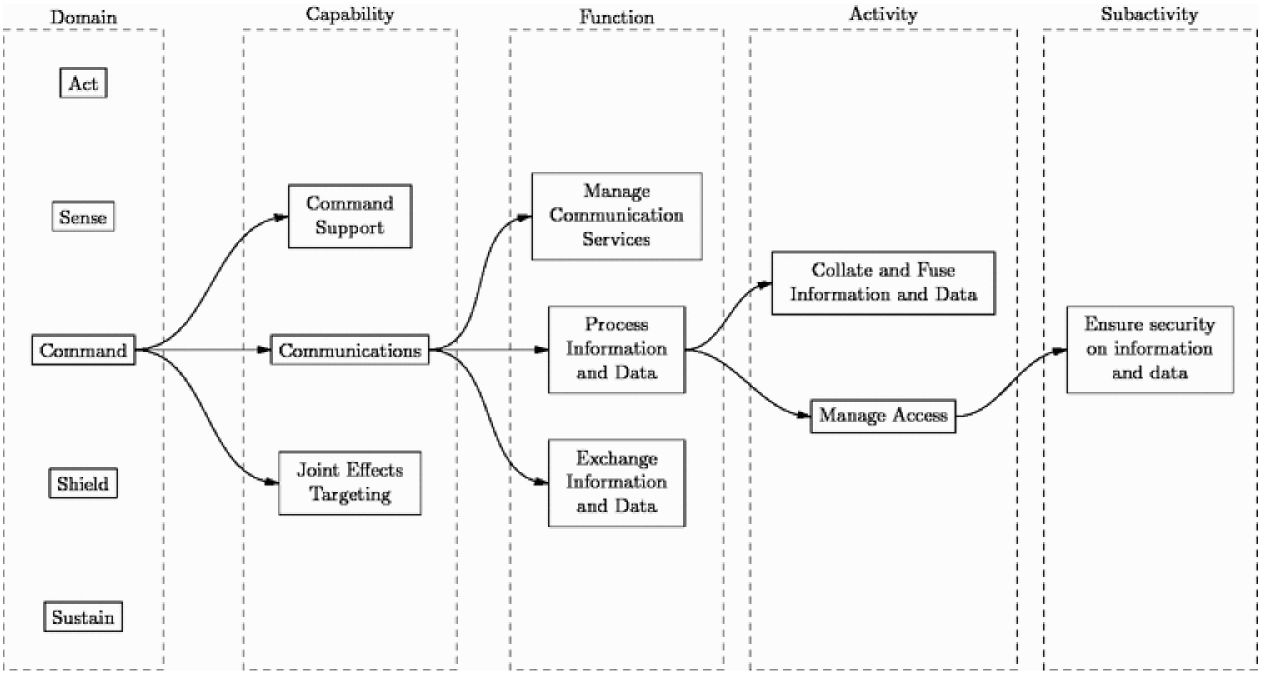


**Figure 5: Capability Framework Example.**

## 3.3 $SC_2RAT$

The Scenario Capability/Capacity Requirements Assessment and Outlook Tool ($SC_2RAT$) is the follow on method to CATCAM. $SC_2RAT$, which uses the capability framework element scores determined in CATCAM, existing and future programmed operational force structure, and force element rotation ratios as input, generates a capability outlook that effectively describes the health of the CF capabilities over time for each force planning scenario. This is accomplished through a three step procedure: first, subject matter experts evaluate the types and number of operational force elements required to perform the Subactivities[12]; second, operational force elements are assigned to Subactivities based upon a set of rules (e.g., force elements are assigned to higher ranked (i.e., higher CATCAM score) Subactivities first); and third, generation of a capability outlook for each scenario, which is a summary of its associated capability adequacies and deficiencies. The first and second steps are repeated for each time period studied where there is a change in the operational force structure.

[12] Any capability framework level could be analyzed, however the second generation CBP analytical process used the Subactivity level as described in section 3.2.

An example of a segment of SC$_2$RAT for a single scenario and time period is shown in Figure 6. The capability framework, along with the Subactivity scores, is shown in the left portion of the tool and across the top is the required scenario information (i.e., duration, rotation length) and the force structure (i.e., force element types, quantity, rotation ratio) for the given time period. The lower right portion provides the ability of subject matter experts to perform the first step in the procedure; that is, to evaluate the type and number of force elements required for each Subactivity. There are two types of evaluations: primary and secondary. A primary evaluation is the number of force elements of a type required from those available in the force structure for a single rotation to perform a Subactivity. A secondary evaluation is similar to a primary evaluation, however rather than requiring the force elements from the force structure the force elements are required from an identified primary evaluation. The purpose of the secondary evaluation is to allow the tool to reflect the reality that a set of force elements may perform more than one Subactivity. As a guide to the evaluations, the measures of capability provided from CATCAM are used to assist the subject matter experts during the evaluations. As an example of an evaluation, 'Conduct CANUS initial planning' is a primary evaluation that requires two of force elements of type FE1 and 'Conduct strategic and operational' is a secondary evaluation (i.e., is linked to Subactivity 1.1.1.1.4) that requires one force element of type FE1. It should be noted that the number of force elements required for a secondary evaluation must be less than or equal to that in the associated primary evaluation.

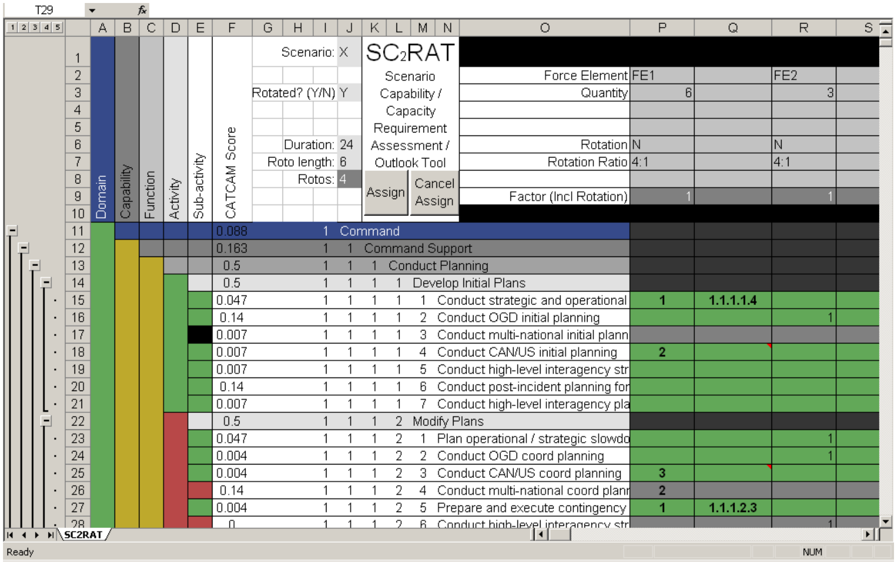


**Figure 6: Example segment of SC$_2$RAT with sample data for a single scenario and single time period.**

The second step in the procedure, which is the assignment of force elements to Subactivities, is performed after all Subactivies have been evaluated by subject matter experts. The assignment heuristic assigns force elements to Subactivities based on their score (i.e., greedy algorithm); that is, force elements are assigned to the Subactivities with the highest CATCAM score with a primary evaluation first, the second highest CATCAM score with a primary evaluation second, and so forth. During each assignment the number of required force elements is checked against the force structure; if there are enough force elements available, then the number required is removed from those available and the Subactivity is labeled green[13] (i.e., adequate capability), else if there are not enough force elements available the Subactivity is labeled red (i.e., deficient capability) and the required force elements are not removed from those available. This assignment heuristic is repeated for each force element type, however once a Subactivity is labeled red further force element assignments are not performed for that Subactivity. It should be noted that the

[13] See column E in Figure 6.

secondary evaluations are not assessed in the assignment heuristic, and are subsequently assumed to be green.

The final setup of the procedure is the generation of a capability outlook for each scenario. An example is shown in Figure 7. The outlook for each year for each Subactivity is taken directly from $SC_2RAT$, and these are subsequently aggregated to higher-levels in the capability framework. The aggregation algorithm is based on the degradation caused by the lower level deficiencies, and each aggregation is assigned a color (i.e., red, yellow, green) based on the degree of degradation (i.e., Subactivity 1.1.1.1.6 degrades Activity 1.1.1 sufficiently that it is deemed a deficiency).

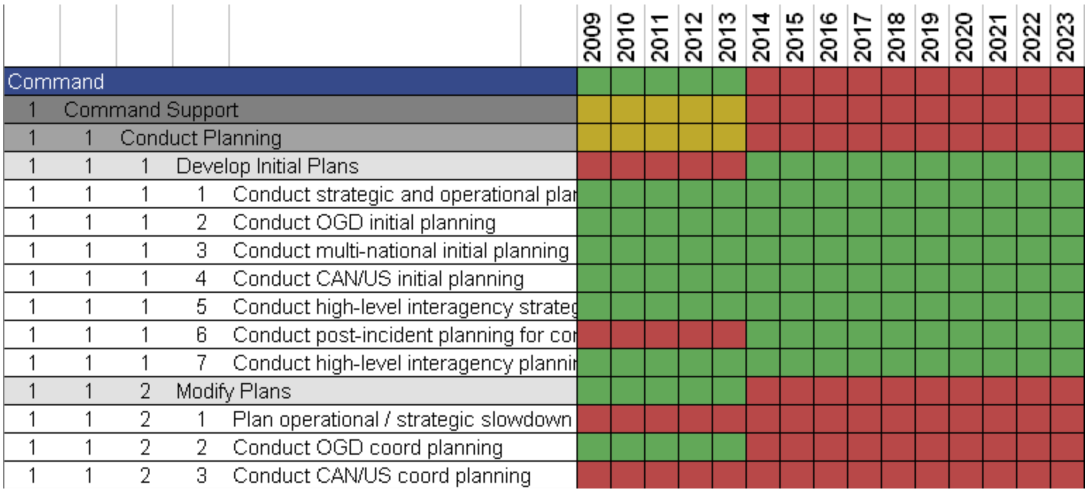


**Figure 7: Example segment of the capability outlook.**

$SC_2RAT$ effectively replaces three methods from the first generation CBP analytical process: the Force Generation and Evaluation (FoRGE) tool [4][6], the Capability Outlook Tool [17], and the Activity-Based Neoteric Deficiency Ranking and Evaluation Workbook (ANDREW) [6]. FoRGE provided a similar construct as $SC_2RAT$ for evaluating the set of force elements that could provide a given capability. However, rather than a specific number of force elements, FoRGE simply allowed subject matter experts to indicate if a force element could or could not provide a given capability framework element. While FoRGE identified which force elements could be utilized, it did not account for the capacity of force elements required as $SC_2RAT$ does. Following this analysis, the Capability Outlook Tool transformed the data collected through FoRGE and transformed it into a capability outlook, similar to the output generated by $SC_2RAT$ shown in Figure 7. Using the capability outlook, in a similar method as to that used in the second generation, subject matter experts created a list of capability deficiencies. ANDREW was then used to prioritize the deficiencies, based on their level of impact to perform the capability framework elements in the scenarios. This assessment is now provided through the degradation calculations in $SC_2RAT$.

## 3.4 Concurrency

While $SC_2RAT$ investigates the force element requirements of individual scenarios, and subsequently the health of the required capability framework elements through the capability outlook, it does not investigate the force element requirements of concurrent scenarios. The Concurrency method [13] provides this insight through assessing the force element requirements of concurrent scenarios and comparing those to the current and programmed force structure. This is done through a three step process: first, calculation of total force elements required, including rotations, for each scenario; second, calculation of the force elements required for combinations of scenarios; and third, determination of force element deficiencies and affluences as a function of scenario concurrency and risk tolerance. There are three levels of risk tolerance that affect the force elements required for a set of concurrent scenarios. The three levels are as follows:

- 'No risk': the required force elements are the sum of the scenario requirements, including rotations (i.e., if scenario *i* requires three force elements of type *x* with a 4:1 rotation ratio and scenario *j* requires two force elements of type *x* with a 3:1 rotation ratio, the total number of force elements of type *x* required for scenario *i* and *j* concurrently is $3 \cdot (4 + 1) + 2 \cdot (3 + 1) = 23$;
- 'Force Generation (low) risk': the required force elements are the sum of the scenario requirements, however this may be reduced by employing rotations from one scenario within another scenario[14] (i.e., if scenario *i* requires three force elements of type *x* with a 4:1 rotation ratio and scenario *j* requires two force elements of type *x* with a 3:1 rotation ratio, scenario *j* may employ two[15] rotations from scenario *i*, thus reducing the total number of force elements required to 17 ($23 - 3 \cdot 2 = 17$); and
- 'Force Generation and Operational (medium) risk': the required force elements are the sum of the scenario requirements, however this may be reduced by employing rotations in a similar fashion to the 'Force Generation risk' assumptions, although with fewer restrictions[16].

The concurrent force element requirements are summarized as force structure deficiencies and adequacies, for various scenario combinations and risk levels over time, as shown in Figure 8. This example shows the three risk levels for six combinations of scenarios. For each risk level/concurrent scenario combination the percentage of required for elements available is shown (i.e., given force generation risk and six concurrent scenarios, approximately 55% of the force elements are not available at the level required). This output is used by subject matter experts to create the risk outlook [6], which describes the risk of the CF not being able to create the concurrent mission effects over time. An example of a risk outlook is shown in Figure 9, where red means that there is a high likelihood of failure, yellow means that there is a chance of failure, and green means that failure is unlikely. The numbers across the top of the figure represent the time period (i.e., year). It should be noted that the risk outlook assumes the 'No risk' risk tolerance level.

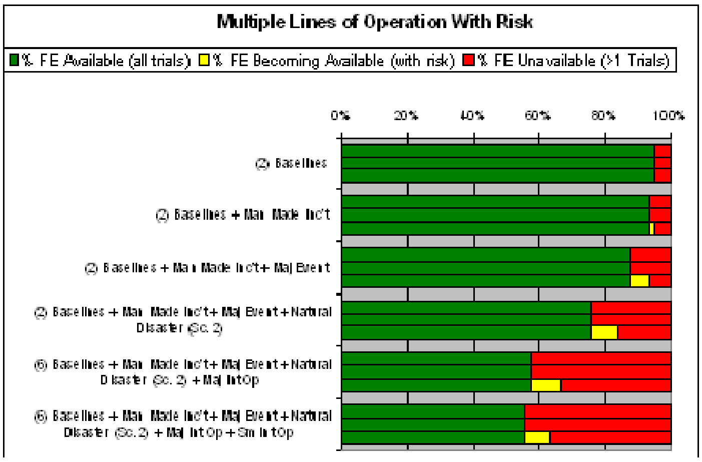


**Figure 8: Example of force element deficiencies and adequacies in concurrent scenarios [13].**

14 It should be noted that currently only the 'Baseline' scenario (i.e., daily domestic CF responsibilities) may employ rotations from another scenario at the 'Force Generation risk' level.

15 It should be noted that at least one rotation must not be employed (e.g., a 4:1 rotation ratio may provide up to two force elements, a 3:1 rotation ratio may provide up to one force element).

16 Whereas the 'Force Generation risk' level may only employ rotations from other scenarios in the 'Baseline' scenario, the 'Force Generation and Operational risk' may employ 'Baseline' scenario rotations in 'Domestic/Continental' scenarios or non-rotated 'International' scenarios.

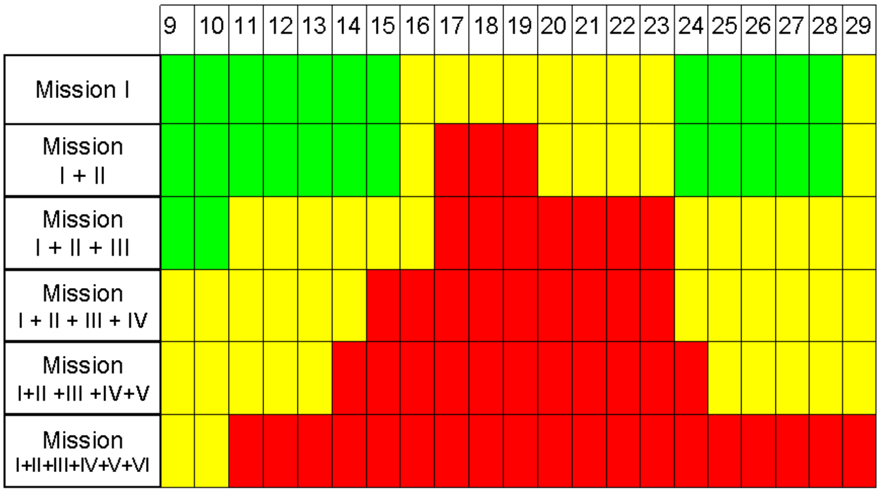


**Figure 9: Example of the risk outlook [13].**

The risk outlook, in conjunction with the force element deficiencies and adequacies, capability outlook, and a level of concurrent ambition are used by decision-makers to determine the set of capability deficiencies that the CF will address. It is this set of deficiencies that is the primary information passed between the ‘capability management’ and ‘capability integration’ components. It should be noted that one deficiency in the set determined by the decision-makers may represent more than one deficiency determined through the analytical methods (i.e., there may be a many-to-one mapping). This is done to reduce the complexity of the subsequent optimization problem.

The Concurrency method was not included in the first generation CBP analytical process. While it has long been recognized that concurrency analysis is an important element of the CBP analytical process [15], due to aggressive timelines and resource constraints the concurrency method was not developed until the second generation.

## 3.5 Optimization

The optimization component of the CBP analytical process provides the ability to search the solution space for non-dominated sets[17] of solutions that best address the identified capability deficiencies, where a solution is comprised of a set of capability investment alternatives [5][6]. The capability investment alternatives are described by a variety of parameters, however the parameters employed in the optimization are as follows[18]: degree to which the alternative addresses its capability deficiency; equivalent annual cost[19]; personnel requirements; and dependencies on other deficiencies and alternatives. Thus, the objective of the optimization is to determine non-dominated solutions that provide maximum military value for minimum equivalent annual cost, where the military value of an individual alternative is based on the importance of the capability deficiency it addresses (i.e., the importance is related to the CATCAM scores of the capability framework elements that the deficiency represents), the alternative’s ability to address its capability deficiency, and the presence of other specified deficiencies and alternatives in the solution. As well, the feasibility of a solution is limited by a set of constraints, primarily the number

[17] Among a set of solutions **P**, the non-dominated set of solutions **P′** are those that are not dominated by any member of the set **P** [18].

[18] Parameters other than those in the list are collected, such as risk (e.g., technology, implementation) and accuracy of cost.

[19] The equivalent annual cost of a capability investment alternative includes several factors, such as acquisition cost, military and civilian personnel salaries, indirect cost for procurement, operations and maintenance, equipment support, basing, and research and development [6].

of military personnel required. As a result of the dependencies between alternatives in a solution, the objective function for military value is modeled by a nonlinear equation, and thus a heuristic is used to determine the non-dominated set of solutions.

As with any heuristic, the non-dominated set found is not guaranteed to be the Pareto-optimal set[20]. An example of a non-dominated and Pareto front (i.e., the solutions of each set exist on their respective fronts) are shown in Figure 10. As such, without a guaranteed upper bound on military value as a function of cost, there is no indication as to the quality of the non-dominated solutions. While the heuristic employed (i.e., constrained multi-objective genetic algorithm[21]) in the second generation has not been modified as compared to its first generation implementation, the quality of the solutions generated have been investigated. Three avenues were undertaken: generation of solutions using a constrained single objective genetic algorithm, evaluation of the algorithmic parameters (e.g., population size, mutation rate) of the multi-objective genetic algorithm to determine their effect on the algorithm's efficacy, and comparison with solutions determined using a second single objective heuristic based on an iterated local search. With respect to the first item, the constrained multi-objective genetic algorithm was converted into a constrained single objective genetic algorithm, such that cost was a constraint rather than an objective. The cost constraint was set at various values and the determined solutions were compared to those found using the constrained multi-objective genetic algorithm. As well, the solutions were used to seed the initial population of the constrained multi-objective genetic algorithm in an effort to direct it towards a feasible region quickly and thus reduce computational time[22]. Through these three avenues the following was determined: the constrained single objective heuristic generated solutions comparable to the constrained multi-objective genetic algorithm; injection of good solutions in the initial population decreased the computational time of the constrained multi-objective genetic algorithm, however did not result in dramatically better solutions; the efficacy of the algorithm was not significantly affected by the choice of parameters; and the second single objective heuristic generated comparable solutions to the constrained multi-objective genetic algorithm. Thus, while the Pareto set was not determined, the confidence in the quality of the solutions has been increased.

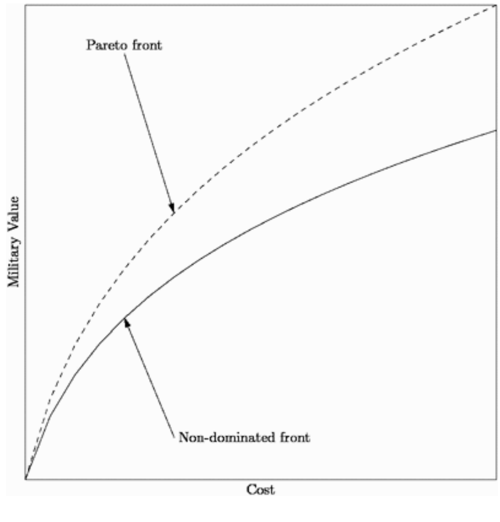


**Figure 10: Example of a non-dominated front and Pareto front.**

[20] The non-dominated set of the entire feasible search space *S* is the globally Pareto-optimal set [18].

[21] The genetic algorithm was implemented using the Phoenix Integration – see http://www.phoenix-int.com/.

[22] A single run of the first generation constrained multi-objective genetic algorithm required approximately 24 hours to perform a single run.

### 3.6 Cost Sensitivity

While the optimization component of the CBP analytical process determines non-dominated solutions (i.e., sets of capability investment alternatives) at various equivalent annual costs, it does not investigate the risk of delivering the solutions due to cost risk. This is accomplished through a follow-on process: cost sensitivity. Given that the equivalent annual cost of each capability investment alternative exists within a distribution (i.e., the lower and upper bounds of the equivalent annual costs are provided for each alternative[15] that are assumed to form a triangular distribution), this information may be utilized to provide further insight into the cost risk of each solution, such as the probability that a solution will not exceed a given funding limit (i.e., solution *x* has an equivalent annual cost of *c*, however there is a probability *p* that the cost will not exceed a cost of *k*). An example of this type of analysis is shown in Figure 11[23], where the triangles (yellow line) represent the percentage of maximum military value delivered (i.e., the non-dominated solutions in Figure 10) and the squares (purple line) represent the probability that the non-dominated solution is achievable for a given funding limit. While other types of analyses exist within the cost sensitivity component, the analysis shown in Figure 11 is representative of the type of information obtained from the cost sensitivity analysis.

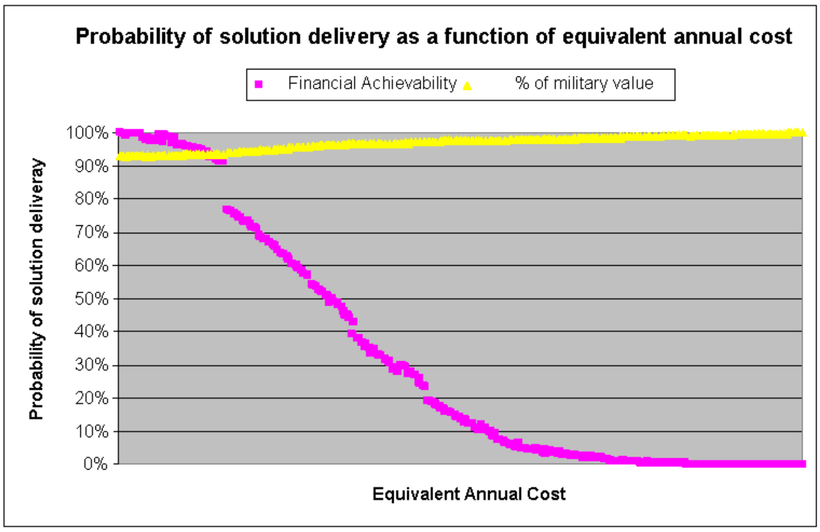


**Figure 11: Probability of solution delivery as a function of equivalent annual cost given a funding limit.**

The information generated through the cost sensitivity analysis aids decision-makers in selecting a solution from those determined through the optimization process. The selected solution, subject to changes made by decision-makers (i.e., due to strategic or political influence), is the approved set of capability investment alternatives and is one of the key inputs to the SCR. Following the approval of the solution, each alternative is mapped to a set of tangible projects. These projects, rather than the capability investment alternatives, form a portion of the input to the investment plan.

The purpose of the cost sensitivity component within the CBP analytical process was not altered between the first and second generation, however the implementation of the component was changed. Cost sensitivity in the first generation was performed using a Monte Carlo simulation [6], where the approximation of the cost distribution of a solution was determined through sampling the cost distributions of its alternatives. While this is a valid method to perform this type of analysis, the second generation employed the mathematical properties of the capability investment alternative's triangular distributions

[23] This figure was provided by Leonard Kerzner.

within a solution and curve fitting to calculate its approximate cost distribution. The primary difference between these two approaches is that the first generation method is stochastic, while the second generation method is deterministic.

# 4.0 NEXT GENERATION ANALYTICAL PROCESS

## 4.1 Overview

Upon completing the application of the second generation CBP analytical process, a review of its features was performed. Several shortcomings of the second generation process and its methods were identified, and may be summarized as follows:

- Lack of considering time when selecting capability investment options, and a lack of including capability divestment and capability sustainment alternatives;
- Lack of a consistent knowledge management system;
- Lack of inclusion of the Generate domain (i.e., those parts of the CF that exist to support and prepare force elements for possible deployment);
- Lack of consultation with decision-makers during the definition of the process outputs; and
- Lack of maintaining a strategic-level view throughout the process.

Subsequently, it was determined that the design and development of the next generation of CBP analytical process may be described by seven development thrusts. These seven development thrusts are:

- Command View - Design and develop an interface between senior decision-makers and the CBP process, in an effort to better help decision-makers enhance their understanding of the process and its outputs;
- Capability Based Planning Analytical Process - Modify the CBP analytical process, such that it includes the Generate domain and produces outputs that are valuable to decision-makers;
- Capability Framework - Modify the existing capability framework as required to facilitate the application of CBP at the strategic-level;
- Generate Domain - Develop the Generate domain to the level of fidelity required to facilitate the application of CBP at the strategic-level;
- Capability Based Planning Database - Design and develop a relational database for storage of CBP data, thus providing a consistent knowledge management system;
- Optimization - Design and develop an optimization technique that selects capability investment, divestment, and sustainment options over time to best meet CF capability requirements and incorporates cost risk; and
- Capability Based Planning Tools - Enhance the CBP analytical methods (e.g., CATCAM, $SC_2RAT$, Concurrency), such as separating the methods and their input/output data, integrating the methods and the CBP database, and developing rules for producing the risk outlook.

## 4.2 Implementation Challenges

There are four key challenges that may impede the design and development of the next generation of the CBP analytical process:

- The need of each development thrust to be cognizant that its design and development is strongly influenced by that of the remaining thrusts;

- The need of senior decision-makers to agree upon the set of expected outputs of the CBP analytical process;
- The need of senior decision-makers to agree upon the degree of fidelity that the capability framework and generate domain must represent; and
- The need to develop the generate domain.

The first key challenge is related to the fact that each thrust does not occur in isolation; as each must make design decisions at the appropriate time to ensure efficient development. Thus, the relationships between the thrusts must be taken into account during project planning. For example, the 'Capability Based Planning Analytical Process' thrust strongly influences the 'Capability Based Planning Tools' thrust (i.e., definition of the process defines the types of tools that are required), which in turn influences the 'Capability Based Planning Database' thrust (i.e., the tools define the type of data that will be stored in the database). Figure 12 shows the influence diagram between the seven thrusts. It should be noted that a relationship between two given thrusts, for example 'Optimization' influences 'Capability Based Planning Database', does not mean that one thrust must be complete prior to a second thrust commencing; rather, that components of the first thrust are required to be completed prior to components of second thrust being completed.

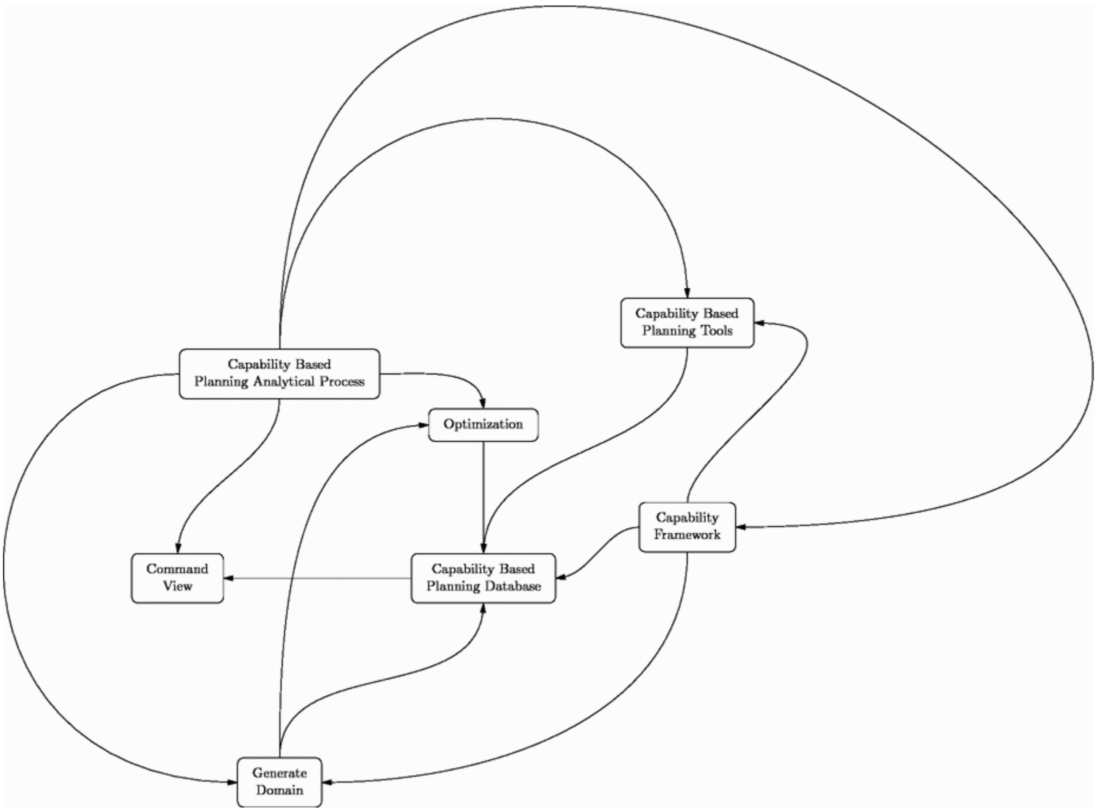


**Figure 12: Next Generation Development Thrust Influence Diagram.**

The second and third challenges are related to the requirement that senior decision-makers must approve aspects of the CBP analytical process (i.e., process outputs and the capability framework). These challenges not only directly affect their respective development thrust, but also affect the remainder of the thrusts (e.g., without a definition of the CBP analytical process outputs, the 'Optimization' thrust can not guarantee that it will produce valuable outputs). While the development of the thrusts may continue without senior leadership endorsement, the resulting outputs may not be accepted.

The fourth challenge is the development of the Generate domain. The Generate domain is large and relatively ill-defined in comparison to the existing domains; it may prove difficult and thus hamper the remaining thrusts. However, design and development of the remaining thrusts may continue, due to that the ‘Generate Domain’ thrust only directly influences the ‘Capability Based Planning Database’ and ‘Optimization’ thrust. These influences may be mitigated through ensuring that each thrust produces products that are flexible (i.e., the CBP database may be expanded to include the Generate domain information).

## 5.0 CONCLUSION

In this paper the second generation CBP analytical process, which exists within the CF FD process, was presented. An overview of each method within the process was discussed; with an emphasis on how the methods work together and their modifications since the first generation. Shortcomings of the second generation CBP analytical process were identified, and an introduction to the proposed next generation CBP analytical process was briefly presented. Key implementation challenges were highlighted.

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