NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

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**STO TECHNICAL REPORT** **TR-SAS-134**

# Improving Defence Investment Portfolio Decisions: Insights from the Literature and National Practice

(Améliorer les décisions relatives au portefeuille d'investissement de la défense : perspectives tirées de la littérature et des pratiques nationales)

Final report.

October 2022

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# The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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# Preface

Initiation of this work came from the Chair's involvement in Canada's implementation of portfolio optimization to prioritize major defence capital investments (with procurement costs greater than 5 million CAD) in 2014. Software developed in-house by Operational Research (OR) team members to support National Defence (ND) strategic planning [1] optimized the combined value promised by new investment deliverables to be funded from the varying unused portions of year-over-year investment budgets going out 20 years. The software used elegant visualizations from D3 graphic libraries to showcase portfolio attributes with bubble charts, tree maps and hover-over pop-ups. It brought drag-and-drop convenience to portfolio adjustments and gave the user control over how long the software spent looking for better investment combinations. It offered a new and compelling perspective to senior leaders, who were previously accustomed to negotiating an all-of-defence value-ranked list of investment priorities behind closed doors and then funding projects from the top down until the entire portfolio budget had been allocated [2].

The principal weakness of the new approach was that the software never selected the largest investments; they had to be dragged in as new constraints around which to optimize the rest of the portfolio. This highlighted the weakest part of the arrangement: the model of the relative value of investment deliverables. The greatest and least possible values that could be assigned to an investment spanned about 1.5 orders of magnitude, but the range of investment acquisition costs spanned more than 3 orders of magnitude. Nothing more expensive than $200 million could compete with the value density of even the least useful $10 million investment. Our model of promised investment benefit was too simplistic, which is not surprising, since defence capital investment modelling remains a challenge in the literature.

Surprisingly, it was not the optimization feature that made the software so valuable, and the weakness of the value model did not interfere with its greatest utility. Unbeknownst to its developers, its principal usage was not to find optima but to learn the limits of which large investments could and could not coexist in the portfolio under the 20 different committed annual budget constraints. Contracted database support staff would drag a large project that had been excluded from the optimum back into the portfolio and see what the software forced out of the portfolio as a result. Sometimes just one project alone rendered the portfolio infeasible, because its spending profile required more money in one year than was left uncommitted from that annual investment budget. The software provided an opportunity cost discovery environment. The most significant result from the software's use was a rapid and dramatic adjustment in service chief expectations of future capability from present government funding levels. These revelations drove critical conversations between National Defence (ND) and government, culminating in the renewed defence policy of 2016 with new funding for defence capability investments.

An important discovery for the Chair was how difficult it was to exploit the detailed technical products of Canada's Capability Based Planning (CBP) process in order to model the relative benefits of capital investments. The questions it was answering were formulated too differently and the analysis providing the answers founded on different assumptions from those emerging from the need to make trade-offs between candidate investments. When SAS-134 began, others at the first meeting were hard pressed to understand how the military judgements offered by their own nation's capability planners could culminate in some of the investment decisions taken. These and similar participant observations engendered a growing sense that the last step of CBP, where capability insights join with cost, budget and defence guidance to produce an affordable capability development plan [3], was the most complex and problematic step, worthy of singular attention beyond the specific difficulty of modelling value well. This report presents the results that attention.

Finally, terminology is always a challenge in international collaborations, and a few recurring issues have emerged. These concern terms like investment, alternative, option, and portfolio, each of which has different usages:

- The term "**investment**" implies that funding has been or will be allocated to it. If not, it might better be called a candidate investment or an investment candidate. In a report about how to select investments for funding, this can become quite tedious, so we use the term for both and rely on the context to clarify whether it is marked for investment or not.
- The term "**prioritized**" usually means recognized has having superior priority, but it can also apply to an inventory of investment candidates that have undergone a judgement of funding-worthiness, a down-selection process, in which case some investment candidates come out of the process with status of "under consideration" changed to "excluded from the Planned Investment Portfolio." We try to use the term to mean simply judged, whether or not it was found wanting.
- In this report, we use the word "**alternative**" to describe an item on a menu from which you will make exactly one selection. Hence, different portfolios of investments are called alternative portfolios. If you select one, you will not be selecting any other – they are mutually exclusive alternatives.
- The term "**option**" has its most frequent usage in project management where a specific requirement may be filled by different investment options identified during the Options Analysis phase in the life of the project. A project calls for a car, and it could be a Fiat, or it could be a BMW, different project options. These may seem like alternatives, except that the actual investment menu also includes "none of the above" – the project may not find a place in the planned investment portfolio. Therefore, "options" will refer to individual investments whose presence in the portfolio is "optional."
- The term "**portfolio**" has been used variously in the OR literature, sometimes including all investment options only some of which will be funded, and sometimes to include only those investments selected for funding. We restrict the use of portfolio to either a set of projects under specific consideration for funding as a group (an alternative portfolio) or a set of projects selected for funding (the selected portfolio).
- The term "**investment inventory**" is used to define the list of all available investment options before any down-selection in the construction of specific portfolios has occurred.
- The term "**project**" will sometimes be used to specify a requirement without saying anything about which of the investment options the project is developing to meet that requirement is to be funded. In general, no more than one project option is funded. This comes up when discussing whether or not more than one project option is admitted to the investment inventory. If not, then funding an investment effectively means funding whichever project option was approved in the transition between options analysis and project definition to meet the requirements the project was created to satisfy. That said, the project inventory could (and in at least one nation does) include more than one option for each project.

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# Improving Defence Investment Portfolio Decisions: Insights from the Literature and National Practice

## (STO-TR-SAS-134)

# Executive Summary

Future uncertainty, complex military system interdependency, the scale of public investment costs necessary to equip military forces and the strongly distinct cultures, perspectives and interests of stakeholders make Defence Investment Prioritization (DIP) among the most difficult decisions any nation makes. Though variants of Capability Based Planning (CBP) are practiced throughout NATO to guide defence planning, there remains the challenge of building an affordable investment portfolio based on realistic costs and budgets.

Several literatures were examined in seeking insight into best practices that could help nations improve DIP decisions and achieve the best possible national and alliance outcomes. The review included the ethical, policy development, capability development, and costing foundations of DIP before exploring the relevant literatures on financial investment, Operational Research (OR), Systems Analysis (SA), Decision Analysis (DA), individual and group biases, and Decision Making under Deep Uncertainty (DMDU). This included an examination of prior NATO SAS studies and specific military applications. We discovered what appears to be a mismatch between assumptions embedded in most of the OR literature on capital investment prioritization and those accompanying DIP decision-making. The OR literature consistently formulates DIP as finding the best mathematical algorithm to construct an optimal portfolio from scratch largely ignoring various real-world constraints including the dynamics of public accountability, governmental processes, industrial base interests, international competition, or the political cost of cancellation that attend defence portfolio decisions. The DA literature offers a broader treatment that explicitly accommodates these and other dimensions of decision complexity. The Systems Analysis literature first developed in the U.S. focuses specifically on DIP decisions, while that of DMDU addresses the complex nature of future uncertainty. From this literature search, we discovered that the DA's "Decision Quality" (DQ) framework offers a practical and well-validated distillation of all the aspects required in a good decision and note its close correspondence with the tenets of SA. The DQ framework provides a set of six perspectives through which nations can examine and evaluate their own decision processes, including those concerned with DIP.

From the portfolio DA literature, a 105-item survey questionnaire on national DIP practices was developed that addresses investment planning time-frames and processes, the development of investment objectives and preferences, benefit modelling methods, the treatment of costs and resource constraints, and the handling of investment interactions and risk. Under the condition of anonymity, we obtained responses from 13 nations – 7 with populations larger than 20 million people and 6 smaller. Results indicated limited application of portfolio benefit/effectiveness modelling methods, a desire for more and better analysis and, in particular, wide diversity in most aspects of national DIP practice. These signalled a need less for better procedures than for over-arching principles to help guide sound long-term defence investment decisions, for which the Decision Quality framework is proposed.

It may prove helpful to use DQ to clarify and manage the organizational, technical, analytical, and uncertainty-based complexities of the DIP problem. The DQ perspectives provide guidance for: DIP problem definition, both before and during the formal decision process; desired attributes to consider in developing

alternative portfolios for consideration; ways to reduce the complexity of benefit evaluation through priority-and preference-based aggregation; avoiding biases through well-informed portfolio information elicitation; insights into the robustness and sensitivity to uncertainty of various portfolios; and valuable decision management processes and execution design.

The study concludes with a brief discussion of implications for the careful integration of OR tools and CBP in DIP decisions, and some limitations of the study including open questions for subsequent work, and a proposal for a follow-on event. Several annexes are included that provide additional insight and supporting materials.

# Améliorer les décisions relatives au portefeuille d'investissement de la défense : perspectives tirées de la littérature et des pratiques nationales

**(STO-TR-SAS-134)**

## Synthèse

L'incertitude de l'avenir, l'interdépendance complexe des systèmes militaires, l'échelle de l'investissement public nécessaire pour équiper les forces militaires et les grandes différences de cultures, points de vue et centres d'intérêt des parties prenantes font de la hiérarchisation des investissements en matière de défense (DIP) l'un des domaines de décision les plus ardus dans tous les pays. Bien que des variantes de la planification fondée sur les capacités (CBP) soient appliquées un peu partout dans l'OTAN pour orienter la planification de la défense, la constitution d'un portefeuille d'investissement abordable sur la base de coûts et de budgets réalistes demeure un défi.

Plusieurs littératures ont été examinées à la recherche de connaissances sur les meilleures pratiques pouvant aider les pays à améliorer leurs décisions de DIP et obtenir les meilleurs résultats possibles au niveau national et de l'Alliance. L'examen a porté sur l'éthique, l'élaboration des politiques, le développement des capacités et les bases d'établissement des coûts du DIP, puis sur l'exploration des littératures pertinentes sur l'investissement financier, les recherches opérationnelles (OR), l'analyse des systèmes (SA), l'analyse des décisions (DA), les biais individuels et de groupe et la prise de décision en conditions de grande incertitude (DMDU). Cela a inclus un examen des études précédentes du SAS de l'OTAN et d'applications militaires spécifiques. Nous avons découvert ce qui semble être une incompatibilité entre les hypothèses de la plus grande partie de la littérature des OR sur la hiérarchisation de l'investissement en capital et les hypothèses accompagnant la prise de décisions de DIP. La littérature des OR envisage constamment le DIP comme la définition du meilleur algorithme mathématique pour construire un portefeuille optimal à partir de zéro, en ignorant diverses contraintes du monde réel, notamment la dynamique de la responsabilité publique, les processus gouvernementaux, les intérêts industriels, la concurrence internationale ou le coût politique d'une annulation, qui se rattachent aux décisions du portefeuille de la défense. La littérature de la DA offre un traitement plus large qui tient explicitement compte de cette complexité décisionnelle et d'autres dimensions y afférentes. La littérature d'analyse des systèmes, qui trouve son origine aux États-Unis, se concentre spécifiquement sur les décisions de DIP, alors que la littérature de la DMDU s'intéresse à la nature complexe de l'incertitude de l'avenir. À partir de ces recherches dans la littérature, nous avons découvert que le cadre de « qualité de la décision » (DQ) de la DA offrait un condensé pratique et bien validé de tous les aspects requis d'une bonne décision et nous avons remarqué sa correspondance étroite avec les principes de la SA. Le cadre de la DQ propose un jeu de six perspectives selon lesquelles les pays peuvent examiner et évaluer leurs propres processus décisionnels, y compris ceux concernés par la DIP.

À partir de la littérature sur la DA, un questionnaire d'enquête en 105 points sur les pratiques nationales de DIP a été établi, qui s'attache aux processus et délais de planification de l'investissement, à l'élaboration d'objectifs et de préférences d'investissement, aux méthodes de modélisation des bénéfices, au traitement des coûts et contraintes de ressources, ainsi qu'à la gestion des interactions et du risque d'investissement. Sous couvert d'anonymat, nous avons obtenu des réponses de 13 pays, dont sept ayant une population de plus de 20 millions d'habitants et six pays plus petits. Les résultats ont révélé une application limitée des méthodes de modélisation des bénéfices/de l'efficacité du portefeuille, le désir d'une meilleure analyse, plus développée, et surtout, une grande diversité de la plupart des aspects de la pratique DIP nationale. Cette enquête a mis en lumière

le besoin non pas tant de meilleures procédures que de principes généraux permettant des décisions d'investissement saines à long terme, pour lesquelles nous proposons le cadre de qualité de la décision.

Il pourrait s'avérer utile d'utiliser la DQ pour clarifier et gérer les complexités – organisationnelles, techniques, analytiques et dues à l'incertitude – de la DIP. Les perspectives de la DQ constituent des orientations pour : la définition du problème de la DIP, à la fois avant et pendant le processus décisionnel officiel ; les attributs souhaités à prendre en compte pendant l'élaboration de portefeuilles alternatifs ; les manières de réduire la complexité de l'évaluation des bénéfices par l'agrégation fondée sur la priorité et les préférences ; l'évitement des biais par l'obtention bien renseignée d'informations sur le portefeuille ; les connaissances sur la robustesse et la sensibilité à l'incertitude de divers portefeuilles ; et les précieux processus de gestion des décisions et la conception de l'exécution.

L'étude se conclut par une brève discussion portant sur les implications, en vue de l'intégration soigneuse d'outils d'OR et de CBP dans les décisions de la DIP, et sur quelques limites de l'étude, notamment les questions ouvertes pour des travaux consécutifs, et propose un événement ultérieur. Plusieurs annexes apportent des connaissances supplémentaires et des éléments à l'appui.

# Chapter 1 – INTRODUCTION TO THE PROBLEM

As nations struggle to recover from a global pandemic that has devastated lives and destroyed economic activity, massive government spending aimed at limiting the damage has shattered fiscal balance sheets. Record deficits and debt will place nations under enormous pressure to trim defence expenditures. To preserve NATO capabilities, hard choices lie ahead that require a sober assessment of security challenges, and robust methodologies to prioritize defence investments. This report outlines what the literature describes as best practice for defence portfolio investment prioritization, and summarizes insights obtained from a survey of actual practice in several NATO and partner nations.

The challenge for allied nations is to affordably advance their defence capabilities to meet national and alliance requirements in a dynamic security environment. A portfolio perspective requires nations to view planned investments proposed by each military service (Army, Navy, Air Force, etc.) from an enterprise level as contributing to overall national and collective defence. Today defence officials face urgent decisions on what investments to include in their defence portfolios. Periodic assessments of future requirements against current force structures help nations identify and evaluate alternative portfolios (combinations of investments) in terms of costs, benefits, schedules, budgets, and risks. Finding a robust mix to meet national and alliance requirements is the heart of the defence investment prioritization (DIP) problem.

We define the DIP problem in more detail in Section 1.1 and what makes it so challenging in Section 1.2, before outlining the rest of the report in Section 1.3.

## 1.1 THE DEFENCE INVESTMENT PRIORITIZATION (DIP) PROBLEM

Different nations formulate the problem in different terms. Indeed, the nature of a National Defence (ND) mandate is that it reflects each nation's unique history and culture. For the purposes of this report, we assume:

> *The goal of DIP is to arrange for delivery of the capital (equipment and related) assets necessary for ND to fulfil its ongoing mandate within available resources, given future uncertainties.*

Investments in defence are among the most complex any nation makes, especially due to the array of uncertainties they face in delivering capable forces. The scale of military equipment and infrastructure costs and the distribution of regional industrial benefits often make them the focus of partisan public scrutiny, occasionally subjecting them to amendments with more political and social than military utility. The aggregation of these effects over an entire national defence investment portfolio makes the resulting trajectory of military capability evolution very difficult to predict and manage. The changing global security environment only adds to this complexity by obscuring the best and most robust scenarios to focus on in developing such a portfolio [1].

## 1.2 CHALLENGING PROBLEM ATTRIBUTES

Determination of funding priorities between competing defence investments comes with significant levels of complexity in multiple dimensions that can only be managed well with careful planning and execution of the decision process. The difficulty of the task comes from several features which are, in combination, unique to Defence.

### 1.2.1 Multiple Conflicting Objectives of Different Priority

Unlike financial investment portfolios, which seek strictly financial returns with acceptable risk, defence investment portfolios must deliver a broad variety of specialized capital assets which, combined with legacy systems, provide national and collective security. In the private sector, capital asset investments can be linked to estimated impacts on business profits and share values, but the value or return on military investments can only be measured against outcomes related to the achievement of intrinsically complex national and collective defence mandates. Likewise, in the private sector investments deliver profits, and while profits from one investment can cover losses from another, in defence where one investment project is designed to fill a certain capability gap, a successful project cannot necessarily make up for problems experienced in another project if they address different capability gaps. Defence investments must also serve alliance and diplomatic relations, which also factor into a nation's defence. While the risk and return dimensions of a financial portfolio can be combined into a single riskless equivalent rate of return, the variety of distinct capability, economic and political goals driving or shaping defence investment priorities cannot easily be combined into a single measure of portfolio merit [2]. Moreover, as part of a public sector enterprise, ND executives are subject to more elaborate accountabilities, sensitivities, and political oversight than their private-sector counterparts, including other-than-military objectives and frequently changing priorities [3].

### 1.2.2 Non-Binary Decisions per Investment Option

While many financial investment options can be assigned almost any amount of money, capital asset investment options are discrete, and involve specific acquisition costs for specific quantities of specific deliverables on specific schedules. There are many different ways to close a capability gap, each one performing differently against the various dimensions of required capability performance, and that also correspond to different levels of priority for inclusion in a future national defence force. Multiple partially-exclusive options may also compete to close a single capability gap [2].

### 1.2.3 Dependencies Among Investment Options

The capability benefit that one investment deliverable provides is routinely affected by other capability solutions deployed into the same theatre. For example, two different investments might generate more benefit in combination than the sum of their individual benefits[1]. They might deliver less overall benefit together than the sum of their individual benefits if they address overlapping capabilities[2]. New platforms, new munitions and upgrades to existing platforms and munitions, command and control, tactics and training can all interact in many-way relationships that invalidate linear assumptions about investment benefit [2]. These are in addition to the cost-based linkages between investments that fixed portfolio budgets impose and the factorial (beyond exponential) increase in complexity due to the number of possible portfolios.

### 1.2.4 Complex Non-Linear Cost Functions per Investment Option

While financial investment options tend to have a fixed cost per unit, this is not so with capital asset investments. In completing any project, the classic tension between quality/performance, speed/schedule and cost is well known and non-linear. There are learning effects that can increase efficiency and reduce marginal costs over time, but also overhead costs associated with extended production timeframes involving specialized staff and facilities. Reducing the number of units delivered rarely delivers proportional savings. Hence, accurate cost estimation ahead of time is accompanied by either significant error margins, design of complex cost models (which eliminates most portfolio optimization software), or both [2].

[1] To illustrate, new or improved artillery guns together with improved artillery munitions might be more beneficial together than the sum of their separate benefits [2].

[2] For example, investments in a new surface-to-surface missile and in artillery improvements may not provide as much benefit together as the sum of their individual benefits because they are partial substitutes for each other [2].

### 1.2.5 Resource Constraints

There are circumstances in which capital investment selection is fairly straight-forward. If costs and benefits of individual investments are known and easily quantified, if investment benefits are measured in the same terms and are generally independent of other funded investments, and investment costs are each small compared to the overall portfolio budget, then the portfolio may be modelled as a linear knapsack. A greedy heuristic that selects investments in decreasing order of benefit-to-cost ratio will usually approximate an optimal portfolio. However, the idea of a benefit-to-cost ratio becomes unclear when investment benefits involve multiple goals that cannot easily be combined and when benefit realization costs include other scarce resources (e.g., people, facilities, time) [2].

### 1.2.6 Uncertainties

The above complexities are all made worse when investment costs and outcomes are uncertain, importing risk. Common risks include [2]:

- Future operational needs materializing differently than anticipated;
- The promised degree of improved operational effect (if any) not materializing; (Actual capability impact of investments can be unknown until well into investment execution, especially when projects include significant research and development costs.);
- True investment costs and delivery schedules deviating substantially from estimates when resources were first allocated;
- Investment managers trading-away elements of investment scope to stay within allocated funding (see Chapter 7 of Ref. [6]); and
- Cost increases across the portfolio, shrinking defence investment budgets (due to economic down-turns, changes of government or loss of public confidence or government confidence in defence management), forcing project cancellations.

### 1.2.7 Asymmetric Risk Aversion Toward Gains and Losses

While there are good arguments for decision makers to obey the axioms of rational choice theory, of which utility theory is a leading example, Tate and Thompson [2] note that decision patterns in the U.S. Department of Defense deviate from these axioms but are much studied and not necessarily irrational. They include the following:

1) Risk-free gains are preferred over gambles with the same expected value;
2) Lives are risked very conservatively, while money and time tend to be risked more freely;
3) Sacrificing a dimension of a required capability is generally unacceptable, regardless of the accompanying benefit to other capabilities.

The latter feature stems from an expectation that intelligent adversaries will adapt to exploit any new weakness [2].

### 1.2.8 Projection Over Long Time Horizons

Major defence investments in new capabilities commonly do not provide immediate benefits. They can take a decade or more to appear and impose operating and support costs for up to five additional decades. This makes capability and resource planning especially difficult. Investment programs look out over multiple budget periods, and if portfolio costs exceed any period's expected budget, the entire portfolio becomes

infeasible. The further out the capability gap forecast, the greater the risk, especially in estimating new threats and those technologies available to counter them. As a consequence, it is difficult to fully evaluate the ultimate merits of today's commitments of funds toward improved capability in the long term – which is the long term opportunity cost [2].

### 1.2.9 The Challenge of Measuring National Defence Investment Outcomes

The fundamental reason for investing in defence capital assets is to achieve better national outcomes. Such outcomes may be described empirically in economic terms where increased stability from robust national and collective security may correspond to greater economic growth. However, measuring socio-economic impacts of defence investments remain a challenge [2], [3], [4]. Moreover, the welfare of the nation goes well beyond economic performance; its meaningful measurement is not obvious; and its sensitivity to factors beyond military control is significant.

### 1.2.10 Organizational Complexity

Portfolio decisions are difficult enough for a single decision-maker with multiple conflicting objectives. When multiple stakeholders have conflicting objectives, obtaining a high quality decision[3] becomes extremely difficult. Within defence, the service chiefs and functional organization heads compete in a zero-sum budget game. Beyond defence, the investment portfolio must serve national domestic priorities which may involve the national industrial base possibly influencing regional economies (i.e., where in the nation will deliverables be built?), and/or foreign policies (i.e., which nation's companies will build it?). Beyond these, investments must also be authorized by governing central agencies (e.g., Ministries of Finance) that may have their own positions on aspects of defence investment, and by the government of the day which will want to carefully manage political risk [3].

A specific example noted by participants at the start of this work is a cultural disconnect between military and resource management communities. It is often difficult to reconcile the strategic capability development priorities articulated by largely military staffs and the capital investment portfolios signed-off by senior ND officials[4]. A related challenge is how few Western nations confirm that implementation of defence investment portfolio decisions actually foster the desired outcomes motivating the policy, and fewer still systematically investigate the extent to which they have even implemented their own defence policies [5].

## 1.3 OUTLINE OF THE REPORT

In Chapter 2, we situate the problem within the broader context of national defence and describe specific preconditions to effective defence investment prioritization. In Chapter 3, we summarize specific literature streams contributing to the understanding of sound defence investment prioritization and their principal contributions. Chapter 4 reports the development and results of a questionnaire surveying defence investment prioritization practices, emphasizing specific instances illustrating the apparent use or non-use of recommended practice from the literature. Chapter 5 provides principles-based guidance from the literature and technical team experience prioritizing defence capital investments. Chapter 6 briefly discusses our findings and presents conclusions and limitations of the study that offer opportunities for future research. Additional material is found in annexes providing more detailed treatments of key topics for the interested reader.

[3] The meaning of "high quality decision" is the subject of Section 3.6.

[4] The U.S. developed its Planning, Programming and Budgeting System (PPBS) in the 1960s specifically to address this challenge, with "Programming" serving as the bridge between military defence planners and senior officials more focused on funding/resource realities.

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# Chapter 2 – FOUNDATIONS FOR PRIORITIZING DEFENCE INVESTMENTS

Each of the following sections addresses a necessary precondition for sound investment prioritization generally managed outside of Defence Investment Prioritization (DIP) processes.

## 2.1 TRANSPARENCY

De Spiegeleire et al. [1] state (p.18):

> *Improving the transparency of defence planning process … can in the end only benefit the platform from which defence negotiates and manages expectations with government and parliament. Without transparency only painful failure will indicate the necessity for change, the costs of which will be very high indeed.*

Since a nation's defence portfolio decisions help shape future national and collective security, it is critical these decisions be tightly linked to security objectives. Moreover, given scarce resources it is imperative that countries achieve the greatest possible value for money. This dual goal can be supported with the help of analytical tools and techniques discussed in this SAS-134 study. However, several risks exist that need to be acknowledged. Clearly understanding these risks, and possible mitigation strategies, can help achieve better outcomes for NATO nations and its partners.

Appendix A.1 (in Annex A) briefly discusses factors in the ethical domain that can undermine a nation's efforts to build a planned investment portfolio that meets military security objectives at the lowest possible cost to taxpayers.

## 2.2 NATIONAL DEFENCE POLICY AND STRATEGY

Defence policy and strategy set the conditions, boundaries, and assumptions for the DIP problem. National approaches to formulating, implementing and reviewing defence policy and strategy, but at higher levels, they follow similar patterns which can be used to check the quality of decisions and reform the supporting processes.

Each nation's defence policy and strategy need to recognize how international dynamics put its interests at risk, what protecting them will involve, and how it will be done. Making clear linkages between policy, strategy, and DIP is not a trivial exercise, made more difficult as global hegemonies shift. In the academic literature, and organizationally, the subjects are often separated and managed semi-independently. This creates challenges in building and maintaining clear priorities and in ensuring alignment and coherence in plans across the full breadth of the organization. This can lead to problems in the delivery and realization of benefits that were promised to stakeholders. Appendix A.2 (in Annex A) provides a summary of how policy and strategy concerns frame the DIP problem and how this framing is part of an enduring cycle for Defence planners. This includes a discussion of several key challenges that confound the DIP problem. The appendix also provides a set of guiding principles for consideration across strategic processes that are commonly used in framing the problem.

## 2.3 STRATEGIC DEFENCE CAPABILITY ASSESSMENT

The intended outcome of capability planning is to provide a basis for an effective investment strategy that develops and sustains identified capability priorities. Nevertheless, within the national defence planning

processes, identification of priorities in future capability development is inseparably interconnected to the existing forces' structure. So, what is routinely the case for national defence planning is a systemic interaction between capability planning and force development. This means that force development reflecting capability requirements must culminate in meeting not only strategic objectives, but should also satisfy resource limitations, manage risk, and be in compliance with other constraints. The development of an effective force package, capable of successfully completing expected operational tasks stemming from a given level of ambition, depends upon building an affordable and realistic capability development plan.

To this end, i.e., with a view to building a realistic and affordable capability development plan, defence planners need an effective mechanism to measure progress in capability development informed by capability trade-offs, assessment of capability strength, identification of capability shortfalls, and their prioritization within the capability planning process. This mechanism is indispensable for follow-up construction of defence investment plans and gathering all necessary defence capability priorities derived from respective security and defence strategies. In this context, the adoption of Capability-Based Planning (CBP) and its application is widely regarded as the appropriate tool. Senior decision makers within NATO and NATO nations look to CBP principles for a comprehensive approach which enables nations not only to derive a capability inventory but also to implement the most cost-effective options in order to get required capabilities [2].

The DIP problem appears when it must be decided how resources will be allocated to implement a capability development plan. This means the focus of this report is very much linked to how individual nations, NATO, and the EU do defence planning. Capability Based Planning (CBP) emerged under that name at the end of the cold war and has been considered the standard for long-term defence planning since. The approach has been adapted to fit each nation's culture, political/military system, and analytical tools and techniques.

The output from a CBP is typically a capability development plan. This consists of a list of capabilities in which nations intend to invest to reach a defined level of ambition for national security. This list of capabilities from the CBP process can therefore be viewed as an input/guide to the Defence Investment Prioritization Problem. Appendix A.3 (in Annex A) describes national approaches to CBP, and briefly outlines NATOs Defence Planning Process (NDPP) and the EUs Common Security and Defence Policy (CSDP). It also discusses how these planning processes are integrated into national defence planning. Critical linkages between CBP and Defence investment portfolio planning, and how interactions among these planning approaches can be improved, are discussed later in the report.

## 2.4 COST ESTIMATION FOR PORTFOLIO PLANNING

Cost estimation is an essential element in long-term defence planning. Cost estimates are needed when making decisions on allocating scarce resources among candidate investments, and also for budgeting purposes. As budgets are annual, the timing of costs/expenditures also needs to be taken into account.

Cost estimation from the life-cycle perspective has been previously studied in a number of NATO SAS reports, such as SAS-069 [3]. However, for portfolio decisions, there may be differences in terms of which of the total system cost categories necessary for the investment to operate successfully need to be included, as well as which life-cycle costs (Operations and Sustainment expenditures, etc.) are included to generate desired capabilities. (See Appendix A.4 in Annex A, for example.) The quality of a cost estimate depends upon the quality of information available about the costed system. Information quality generally improves as the system's properties, delivery schedule, specific usage and service life are discovered and are more precisely defined. Complicating cost projections are political incentives and the short shelf-life of political capital that can drive a preoccupation with near-term costs and short-term solutions, with a bias towards receiving more immediate benefits or returns on investment that may contribute to a more favourable political narrative.

Because of all these uncertainties, cost estimates are stochastic variables. Contingency funding is one way to hedge to reduce cost overrun risk. However, this reduces the ability to fund other valuable investments, and may reduce the efficiency and effectiveness of the investment due to end-of-period contingency reallocation and the requirement to control costs. These complexities and risks have helped create a market to lease major assets, so a nation does not have to own or maintain the equipment. This shifts both up- and down-side risks into private hands for a fee. Yet, outsourcing and public-private partnerships have their own risks. (See the final report of SAS-112 "Public Private Partnerships in a NATO Context" [4] and Chapter 9 in NATO's 2010 Building Integrity and Reducing Corruption in Defence: A Compendium of Best Practices [5] for more information.)

An important aspect of investment costing includes ensuring consistent costing policy and practices across programs. The payoff includes better budget estimates, and better investment decisions, which can lead to more affordable and effective defence programs with which to guarantee our national and collective security. A more extensive treatment is found in Appendix A.4 of Annex A.

## 2.5 CONCLUSIONS

National Defence culture, policy and strategy, strategic capability assessment and investment costing each play critical roles in protecting, orienting, calibrating, and quantifying portfolio decisions, though they each may extend over timeframes somewhat distinct from DIP decisions. With these pre-existing problem dimensions summarized, we turn in the next chapter to the literatures relevant to sound DIP decision-making.

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# Chapter 3 – SOURCE LITERATURE STREAMS

Defence Investment Prioritization (DIP) can be viewed as a special case of several different larger problems, each with their own literatures contributing insights to the topic. This chapter describes each contributing body of literature and briefly summarizes the principal contributions of each. Most of these streams are presented in greater detail for the interested reader in the appendices of Annex B.

## 3.1 FINANCIAL LITERATURE

Though different in some obvious ways, defence investments are similar in a few ways to purely financial investments. The financial literature establishes important principles that are analogous to those that govern defence investments. These include the time value of money, which is crucial when comparing costs over time. They also include the relationship between risk and return, and how it can pay to invest, even when cancellation is not improbable if done with purpose and discipline. Appendix B.1 (in Annex B) gives a fuller treatment of similarities and differences with specific insights from the financial literature on net present value, the nature of investment risk, and investing for resilience.

## 3.2 OPERATIONAL RESEARCH

Assuming the candidate investments are discretely defined and measured in the same units, the problem of how to select the best investments to fund in a portfolio is readily formulated mathematically as a Mixed Integer Program (MIP). The complexity of defending national interests successfully and sustainably over the long term involves many simultaneous objectives, calling for a Multicriteria Decision Analysis (MCDA), a standard category of tools in the operational research toolbox.

Most ND organizations have access to specialist groups of experts in computational strategies to inform leadership decision making. Called Operational Research (OR) in most of NATO[1] , this group of capabilities first took shape in WWII, and has grown from using computational methods to solve problems of military effectiveness to address a much broader range of practical problems centred around getting the best value out of limited resources. Its academic emphasis has been on computational challenges, seeking optimal answers where the limited resources were computing power through the creation and advancement of algorithms. Non-academic OR practitioners seek to leverage the best algorithms to find optimal strategies in the use of government or business resources to generate desired program or commercial outcomes. A paper documenting the approach for the Portuguese navy provides a good background survey of the portfolio optimization literature (Simplício et al., 2017) [1]. Besides Canada's experiences noted in the Preface (Rempel and Young, 2015, 2017) [2], [3], a recent survey (Harrison et al., 2020) [4] lists dozens of other examples.

Appendix B.2 offers a brief treatment of the defence investment prioritization problem from the operational research perspective.

## 3.3 PREVIOUS NATO SAS LITERATURE

This section briefly summarizes and contrasts previous work completed under the Systems Analysis and Studies panel of the NATO Science & Technology Organization that is most relevant to the present study.

[1] In the US, the more common term is Operations Research, sometimes combined with Systems Analysis as in the military profession of ORSA.

### 3.3.1 Cost Estimation

Cost estimating is a critical component of defence portfolio investment decisions and has been extensively studied in at least five previous SAS reports. These reports provide in-depth coverage of cost estimating from multiple points of view. These include Life Cycle Costing (LCC), cost estimating methods, and concerns about accuracy and risks (including possible biases) in cost estimating. Instead of reiterating these issues, we refer readers interested in LCC or related cost estimating issues to review these previous efforts. An element of this study, discussed in Section 2.4, involves challenges when costing a defence portfolio, which will only be a part of LCC cost estimation, spanning at least system acquisition or upgrade phases and possibly more depending on the nation.

The SAS-054 report entitled "Methods and Models for Life Cycle Costing" (2007) [5] continues work begun by the SAS-028 research task group and the SAS-034 symposium, both on cost structure and life cycle costs for military systems. Their report offers a comprehensive overview of the application and use of life cycle costing from the early conceptual phase of a product's life cycle through to disposal. The report contains a review of cost forecasting methods and models together with several examples that provide comprehensive guidance in the application of life cycle costing, with a particular focus on multinational programmes.

The SAS-069 report entitled "Code of Practice for Life Cycle Costing" (2009) [6] builds on the SAS-054 work and provides a practical guide for the use of life cycle costing methods and models. SAS-090 entitled "Cost Efficiency Implications of International Cooperation" (2015) [7] focuses on cost savings achievable in international cooperation projects.

The SAS-076 report entitled "NATO Independent Cost Estimating and the Role of Life Cycle Cost Analysis in Managing the Defence Enterprise" (2012) [8] also builds on previous SAS work on LCC. An important finding of SAS-076 is that many existing models and processes within NATO fall short of the ideal goal of addressing all strategic requirements, as well as the capabilities and costs of every essential component of the portfolio. In fact, SAS-076 (p. 3) emphasizes that portfolio analysis, the focus of the present study, is a promising method to improve defence business practices by analysing a complete group of systems, rather than focusing on acquisition programs one at a time.

### 3.3.2 Long-Term Defence Planning

Ideally, a selected portfolio of defence investments should fulfil long-term defence capability requirements that serve national and alliance defence policy and strategy objectives. Preparations for this approach to investment portfolio decisions are discussed in the current study in Section 2.2 on national defence policy and strategy, and Section 2.3 on strategic defence capability assessment. Highly relevant to these are previous work found in the SAS-025 "Handbook on Long Term Defence Planning" (2003) [9], SAS-072 "Capability-Based Long Term Planning" (2009) [10] and SAS-096 Part II on "Capability Planning" [11].

According to SAS-025 [9], long-term defence planning takes national security interests and objectives as inputs and typically produces 10 – 30 year projections in the form of force structure development plans as outputs. Ideally, fundamental objectives and required capabilities are clearly articulated in a policy document and endorsed at the highest level. Importantly, defence objectives need to be formulated in line with overall financial and other resource limitations, although these are problematic to forecast more than a decade in advance. The size of future operating budgets is another key input or constraint to long-term defence planning. SAS-025 proposes a 'best practice' model that is the product of a critical review of the strengths and weaknesses of NATO and national processes. The report introduces resource-based planning as one possible approach. The defence budget determines the size of the defence force, the level of technology that can be implemented in the force, and the level of readiness that can be maintained by the force. However, SAS-025 work addressing plans 10 – 30 years in the future does not specifically consider the more specific defence investment planning problem sometimes called programming in which cost, benefit and risk information is reconciled with near-term budget forecasts.

The collection of materials presented at the SAS-072 Specialists' Meeting in Norway on "Capability-Based Long Term Planning" [10] addressed national implementations of long-term defence planning and the migration toward capability-based methods. Topics addressed by the 11 papers presented spanned the full range of issues to be managed when prioritizing defence capital investments and included perspectives from the UK, BUL, CAN, NOR and NLD, including some treatment of investment portfolio design, without touching on reviews of existing portfolios.

The SAS-096-Part-II report on "Capability Planning" (pre-release) [11] describes outcomes of analyses aimed at identifying current approaches to capability planning as applied through NATO and EU planning structures, as well as by nations. The analysis points out the fact that a significant number of NATO nations and EU member states implemented their national approaches to capability planning to specifically reflect national needs and interests. This supports the approach taken by the current study to conduct a survey on national practices in portfolio investment planning decisions.

### 3.3.3 Improving the Economic Performance of Defence

The SAS-063 report entitled "Benchmarking Studies and Capability Costing" (2011) [12] discusses cost-effectiveness benchmarking between defence expenditure classes and resulting capabilities. While this informs our study regarding longer-term impacts of portfolio decisions on capabilities, it does not directly address approaches to make those decisions.

The great recession of 2008 was the background for the SAS-113 report entitled "Future Defence Budget Constraints: Challenges and Opportunities" (2016) [13]. The report includes a review of various macroeconomic impacts of the financial crisis, and strategies adopted by Member Nations to mitigate those impacts. This reveals some valuable lessons for the management of defence resources. SAS-113 proposes a framework that organizes country contributions, and the focus of their defence management practices into five broad categories designed to assist Member and Partner Nations to better shape their responses to future budget constraints, safeguard national security, and support the Alliance. The categories are Planning; Programming; Budgeting; Execution; and Assessment. The analysis suggests Member Nations facing fiscal stress naturally tend to focus more on "efficiency" and less on "effectiveness," or more on how they spend their money (Budgeting and Execution), and less on how investments contribute to capabilities (Planning, Programming), and the resultant outcomes (Assessment). The main focus of our study is related to the "Programming" category. This is the heart of the Planned Investment Portfolio decision problem, but also critically depends on "Planning" (clarifying defence policy/strategy, identifying capability gaps, etc.), and feeds into "Budgeting" (recognizing fiscal and other constraints).

The SAS-096-Part-I report entitled "Performance Management in Defence Organisations" (2020) [14] reviews the use of performance measurement and management practices in NATO and partner nations. The report proposes a new framework for strategic-level defence performance management. We note the utility of such frameworks for investment benefit modelling by tracking the functional impact of capital investment deliverables on corresponding aspects of defence performance. Several insights from this exercise merit reflection, discussion, and future research. For example, SAS-096 found that more attention is generally paid in defence organizations to the measurement of means (i.e., resources), rather than ways ("efficiency") and ends ("effectiveness"). Moreover, several nations struggle to define clear objectives and measures related to national interests. Our survey of nations tends to support this finding. In order to address this challenge, our report introduces the Decision Quality construct as a possible approach to help clarify decision objectives.

The SAS-109 report entitled "Risk Assessment Guidebook for Defence Acquisition Programmes" (2018) [15] provides an in-depth analysis of risk assessment, including a guidebook of best practices for defence acquisition risks, and trade-off analysis regarding cost, schedule, performance, and operational aspects of acquisition programmes. The work is directly relevant to sections of the current study, which include risk

analysis but goes into more depth, although from the vantage point of individual programs and not an entire portfolio. The study is a reminder to portfolio decision makers that two of the principal risks to portfolio benefit realization are project managers trading away performance to control costs and schedules, and investment cancellation to restore portfolio affordability. Portfolio decisions need to document the portfolio performance priorities motivating its selection over alternative portfolios, and to ensure strategic value is not inadvertently lost due to tactical decisions of project management.

### 3.3.4 Performance Analysis Options

The SAS-125 report entitled "Comparative Analysis of National Acquisition Processes" (2021) [16] is intended to help nations improve their national defence Acquisition Processes (APs) through lessons learned from other nations. Their survey identifies important differences as well as similarities in acquisition processes between the responding nations. In contrast to SAS-125 which compares nations' individual acquisition project decision processes, our survey does so from the portfolio perspective.

The SAS-093 report "Analysis Support Guide for Risk-Based Strategic Planning" [17] in some sense comes closest to the subject of our work. It addresses the creation of a multi-year force structure development plan that addresses all of "the required changes in the total force structure (capabilities and supporting manpower, equipment, infrastructure, etc.) for all the years in the planning period", which necessarily includes capital investment prioritization as a sub-problem. Their work develops a framework enabling the systematic treatment of risk throughout every phase of the process from preparation for planning through to implementation and lessons learned for next time. The report is oriented to the needs of an analyst on whom a defence planner relies heavily for decision support. The report catalogues a broad array of techniques applicable to different types of risk. While it is not concerned with how the plan is developed, which is more the focus of the present work, it does provide menus from which to select useful risk-focused techniques.

Finally, the SAS-087 report entitled "NATO Guide for Judgement-Based Operational Analysis in Defence Decision Making" (2012) [18] provides a collection of analysis techniques that are useful when decision problems that are not well enough structured or understood to suggest a specific method able to guide the decision. It is directed to analysts who must support such decisions, focuses on the stages and roles that can be needed in a soft OR analysis, and guides analysts through the issues they will have to confront if their work is to achieve validity, credibility, and client acceptance. The Guidebook orients analysts to problems with less structure and potentially greater complexity than investment prioritization and singles out for mention some of the techniques offered here in Chapter 5 (multicriteria analysis, causal networks, AHP, influence diagrams, decision trees). The Guidebook techniques are generic and broader than the specific category of problems addressed here. It is also not addressed to the decision maker who must decide where and how much more analysis is needed. The report is a more exploratory cousin to the NATO Alternatives Analysis Handbook [19].

The current work has also benefited more specifically from participation by some of those who authored the above in our team. In particular, Col Zdenek Petras co-authored the SAS-090 report on cost efficiency and international cooperation and chaired SAS-096 applying performance measurement to military output. Dr Steele also wrote a case study for Part II of the SAS-093 report on managing risk in strategic planning. Prof. Francois Melese served as second reader and editor of the SAS-113 report on national responses to constrained defence budgets.

## 3.4 SYSTEMS ANALYSIS

After WWII, much work was done on an approach called Systems Analysis for allocating resources to defence investments. In the U.S., it developed within the RAND Corporation in the 1950s and brought by a

dedicated staff from RAND into the Office of the U.S. Secretary of Defence in the 1960's. Fisher's 1970 report [20] offers the following description:

> *Systems analysis may be defined as inquiry to assist decisionmakers in choosing preferred future courses of action by (1) systematically examining and re-examining the relevant objectives and the alternative policies or strategies for achieving them; and (2) comparing quantitatively where possible the economic costs, effectiveness (benefits), and risks of the alternatives.*
>
> *It is more a research strategy than a method or technique; and in its present state of development, it is more an art than a science, although scientific methods are utilized wherever possible. In sum, Systems Analysis may be viewed as an approach to, or way of looking at, complex problems of choice, usually under conditions of uncertainty.*

Alain Enthoven's six tenets of Systems Analysis were published in his 1971 book with K. Wayne Smith, How Much is Enough? republished in 2005 [21] and quoted by Davis (2014) [22]:

1) Decisions should be based on explicit criteria of national interest, not on compromises among institutional forces.
2) Needs and costs should be considered simultaneously.
3) Major decisions should be made by choices among explicit, balanced, feasible alternatives.
4) The Secretary of Defense should have an active analytic staff to provide him with relevant data and unbiased perspectives.
5) A multiyear force and financial plan should project the consequences of present decisions into the future.
6) Open and explicit analysis (including transparent data and assumptions), available to all parties, should form the basis for major decisions.

Systems Analysis was implemented in the early 1960s in the U.S. Department of Defense as the "Planning, Programming and Budgeting System" (PPBS) and continues to be used to this day to build U.S. defence budgets. The main antecedent to Systems Analysis emerged in the UK under Sir Winston Churchill whose team of scientists and economists led by F.A. Lindemann enabled him to cope with conflicting resource demands as First Lord of the Admiralty and then as Prime Minister throughout WWII. The power of their analysis to pierce through the veil of bureaucratic secrecy in which military resource requirements were shrouded triggered in the Royal Air Force (RAF) a determination to double-down on its own analysis investments in a sort of analytical arms race with the Prime Minister. This contest was noted by U.S. Air Force (USAF) officials who observed it, which led to the establishment of the RAND Corporation with USAF, academic and Ford Foundation sponsorship [23], [24]. RAND personnel, particularly as economists got involved, developed the approach now very influential throughout the U.S. government where it more commonly goes under the name "policy analysis" [25]. Appendix B.3 narrates the development of Systems Analysis. Enthoven and Smith [21] document its evolution during its first decade under the U.S. Secretary of Defence. Davis's "Analysis to Inform Defense Planning Despite Austerity" (2014) [22] illustrates the pragmatic evolution of the discipline in a contemporary publication. He supplements Enthoven's list of six with three additional tenets:

7) Decisions should confront "deep" uncertainty and disagreement.
8) The planning process should ensure creative and effective collaboration across strategy, operations, technology, programs, and budgets.
9) The planning process should provide for monitoring, feedback, and adaptation.

## 3.5 DECISION ANALYSIS

As seen in Chapter 1, attaining clarity on how to best allocate resources to long-term defence investments is not simply or even first a computational problem, which can only be as meaningful as the correspondences between the populated model and the outcome dynamics most relevant to decision-maker and stakeholder intent. Classic Operational Research has tended to assume that the problem is already well-defined and modeled, but getting to that point with complex multi-stakeholder, multi-objective decisions facing many dimensions of uncertainty can be extremely difficult [26].

The origins of MCDA are not in operational research but, as the name "multicriteria decision analysis" implies, in the discipline called Decision Analysis (DA). The DA discipline focuses on how to manage multiple sources of complexity impacting proper recognition and selection of decision alternatives that best serve what a decision needs to achieve, including analytical and organizational challenges. DA addresses both the design and preparation of useful computation and the careful interpretation of results to ensure the actual problem is not pushed aside by simplifying assumptions and the bounded rationality of human reasoning. Appendix B.4 (see Annex B) offers a brief listing of the most common individual and group biases.

The Decision Analysis literature constitutes a broad and mature body of knowledge related to Operational Research but distinct from it in that its focus is not first on algorithms and computational efficiency but more broadly on understanding and characterizing the nature of the decision to be made and the uncertainty and other sources of decision complexity it must confront, including many things that can impact desired decision outcomes. Decision Analysis ensures decision makers identify the real problem, articulate what the solution needs to achieve, properly explore the possibility space, are realistic about the information they have and what it indicates about alternative outcomes, and helps them prepare for successful implementation [27]. See Appendix B.5 in Annex B for a brief introduction to Decision Analysis.

Within Decision Analysis has emerged the sub-field of Portfolio Decision Analysis, focused specifically on resource allocation problems, whether between investments or ongoing programs [28], [29], [30].

## 3.6 DECISION QUALITY

A defence investment portfolio can be thought of as the current state of a periodically revised long-term bet or wager against future threats. Chapter 1 outlines the complexity of decisions to revise that bet and highlights just some of the factors bearing on success. The future's unavoidable uncertainty means that time continually degrades the match between intended and expected outcomes. The importance of those outcomes demands ongoing vigilance and periodic portfolio revision toward their attainment.

The various national contexts represented within NATO (e.g., national histories, values, cultures, politics, and constraints) mean that what might be a useful decision approach for one nation may be less useful for others. Yet, there is broad agreement in the Decision Analysis community on fundamental attributes of good decisions and on the variety of factors that can undermine efforts to realize intended outcomes. Therefore, recommendations for DIP presented here are not given in terms of procedure but, rather, principle – desirable qualities to be built into not only investment prioritization decisions but any other complex, high impact decisions of long-term consequence.

The Decision Quality construct drawn from the Decision Analysis (DA) literature concisely categorizes the distinct directions in which any complex decision can go wrong and provides a strong and practical framework within which Decision Makers (DMs) can limit this occurrence [31]. For these reasons, the Decision Quality (DQ) construct is offered here as a recommended approach for decision makers who must periodically update their investment portfolios [32].

The Decision Quality (DQ) construct is a six-dimensional diagnostic tool based on well-established DA principles that underpin successful decision making. In essence, a high quality decision efficiently maximizes the likelihood of attaining the most desired outcomes by purposefully using only the needed and available time and resources. Although there are some logically sequential relationships between its dimensions, it is not a procedure, but rather, a set of perspectives or lenses through which to view what has been achieved at any point in a decision process, and to guide efforts toward what is most beneficial to help attain desired outcomes. A high quality decision is identified when all six DQ dimensions are at the point where the cost of further improvement exceeds any expected added benefit [31].

In brief, the six dimensions of DQ are as follows:

1) The decision Frame (defining the decision context and boundaries: what must be decided and why);
2) Creative, feasible Alternatives (representing the best of the decision possibilities);
3) Clear Values and trade-offs (reflecting preference priorities)[2];
4) Relevant and reliable Information (providing a basis of known quality for linking alternatives to expected outcomes);
5) Sound Reasoning (using the information to evaluate alternatives against priorities); and
6) Commitment to action (including plans to manage significant risks).

Essential relationships between these six dimensions are illustrated in Figure 3-1. Appendix B.6 in Annex B describes the Decision Quality construct in detail and guides its application for difficult decisions. Spetzler et al. (2016) [31] provide a very readable guide to DQ. McNamee and Celona (2008) [33] present DQ among a full set of other standard Decision Analysis techniques.

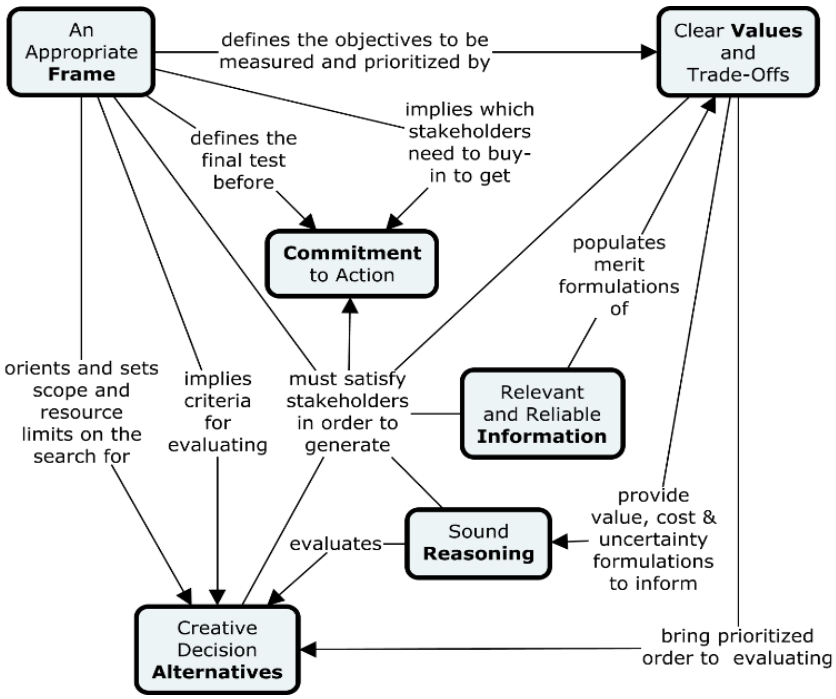


**Figure 3-1: The Main Logical Relationships Between Decision Quality Dimensions.**

[2] We have changed the order of the six DQ dimensions slightly in this report from that published in the sources used here, putting Information after Values and Trade-offs instead of before, because it seemed to suit the application made in this report. This does in no way changes its applicability to other problems, since it is not a procedure.

## 3.7 PROCESS MODELS FOR COMPLEX DECISIONS

As noted above, decisions to update a Planned Investment Portfolio (PIP) include several features that make them challenging:

- Redirecting millions of Euros to be expended over a decade or more is rightly called a "big" decision and should be taken very carefully and deliberately.
- Since ND success depends on highly specialized and interacting legacy assets combined with new investment deliverables successfully meeting the materiel demands of a highly uncertain future, the decision requires the support of an experienced analysis team with broad defence expertise.
- If investment risks are to inform portfolio selection, project and portfolio management experts must be involved to identify the most likely potential outcomes of risky investments.
- The discrete or "lumpy" nature of capital investments means the revised portfolio will promise more satisfaction for some and less for other defence communities, each with different and conflicting values and priorities. Broad stakeholder understanding and support for the ultimate allocation of resources is an important decision outcome, requiring skilled and neutral facilitators.

A decision process building in all these recommended features can be particularly expensive in productive person-days to execute. The development of shared understanding of the most important requirements and strongest alternatives will sometimes be subject to participants being pulled away in the middle and replaced by others, which requires careful documentation of intermediate decision products as the process unfolds. An efficient and robust decision process achieving all these objectives needs to be carefully structured. The literature offers two distinct but versatile decision paradigms for complex decisions in general, and for portfolio decisions in particular [34], [35], [36].

In brief, the first decision making process is Decision Conferencing (DC) (Phillips, 2007) [37], in which an impartial facilitator over the course of at least one two-day event leads decision makers and stakeholders through a specialized software-supported interactive and iterative process of clarifying the problem, eliciting insights, making judgements, exploring implications, raising and exploring objections and surveying the available scope for agreement. Decision Conferencing is described in more detail in Appendix B.7 of Annex B.

The other decision model is called the Dialog Decision Process (DDP) [38], a carefully bounded and sequenced series of meetings between an analysis team and a decision making body, each with well-defined roles, memberships, competencies, tasks, and responsibilities. The DDP is diagrammed in Figure 3-2 and described briefly in Appendix B.8 of Annex B.

The principal differences between these two approaches are the time frame over which the decision is reached (DC is more compressed with less nuanced modelling), and facilitation and analysis (in DC, usually provided by a single person, often but not always a contractor from outside ND). A DC approach works best on "hot" issues of broad and immediate concern and, by its responsiveness to individual participant concerns, can create strongly shared understanding, sense of purpose and commitment to a way forward. The DDP takes longer, affords more time for deliberation and is able to address analytical complexity more robustly, but may not generate the social dynamics that can make DC so effective. Both DDP and DC offer structured approaches to set up the deliberations necessary to minimize risks of narrow decision framing and the illusion of decision quality, and to avoid the agreement trap, comfort zone bias, and advocacy/approval myths described in Appendix B.4 on biases [31].

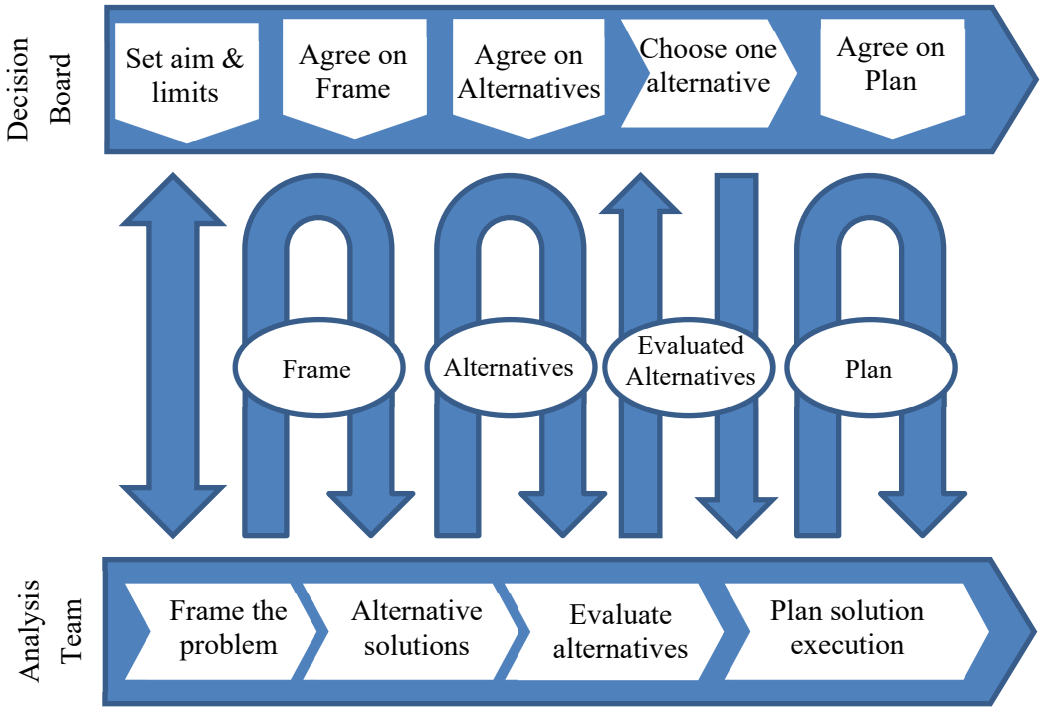


**Figure 3-2: The Dialog Decision Process described in Ref. [31].**

## 3.8 DECISION MAKING UNDER DEEP UNCERTAINTY

To quote a recent RAND Corporation study [39],

> *Defense planning faces many difficult and conflicting requirements. It must allow detailed comparisons among many complicated options, so that the nation can reliably and cost-effectively meet its military needs. Defense planning needs to enable coordination among large, complicated organizations. It needs to guide investments, some of which have years-long lead times. It is expected to provide transparency and accountability to the public. And it needs to recognize that most long-range predictions are wrong and that the future is sure to surprise* [39].

Defence planning in the West has used planning scenarios as a way to span, segment, and distil to essentials an uncertain future, but significant future surprises most often originate outside the dimensions along which scenarios are designed. Hindsight bias makes it easy to forget how barely imaginable now-familiar events were before they happened.

The past three decades have seen new methods and tools for systematically bringing what we know and think to bear on what we need to know but don't. The first of these methods was Assumption-Based Planning (ABP), developed between 1989 and 1993 by the RAND Corporation at its Arroyo Center to help the U.S. Army with its long- and mid-range planning. It focuses attention on identifying the assumptions underpinning the success of some fully developed plan (such as an investment portfolio), and then considering the types of events under which these underpinning assumptions would be negated. Following this, ABP seeks to identify:

1) Signposts to be monitored that indicate an assumption is nearing negation,
2) Shaping actions for implementation to shift the situation toward a more favourable state, and
3) Hedging actions able to limit the losses due to failed assumptions [40].

The decade following ABP's development saw its extension at the RAND Pardee Center in the development of Robust Decision Making (RDM). RDM develops as fully as possible a set of assumptions that may or may not hold in the future, uses exploratory modelling to evaluate an initial variety of policy options in the worlds implied by every possible combination of those assumptions, and then scenario discovery to identify groups of outcomes sharing common performance-relevant features, and the policy factors driving those outcomes. From these initial modelling explorations, trade-off deliberations can occur, and hybrid policies can be designed to launch another iteration of exploratory modelling and scenario discovery [33].

### 3.8.1 DMDU for Defence Investment Prioritization

It must be remembered that long-term defence capital investment, at least for larger nations, is one type of move in a larger strategic game in which one's actions inform those of one's enemies. Methods that manage a future conceived as the result of impersonal or even broad social forces will not be sufficient for determining policy that must counter intelligent adaptive adversaries. There has been military push-back against RDM because it tends to discount worst-case scenarios as just one of many equally unpredictable outcomes. A portfolio that performs well against most things can miss a few key elements needed to counter threats of specific military concern [41]. Hence, future elements that cannot be known must be carefully distinguished from those that can, such as adversarial shaping of the future into domains against which allied performance may be weaker.

Both ABM and RDM have been applied to military long-range planning and recognized as having potential to mitigate future uncertainties in the evaluation of long-term decision alternatives. Appendix B.9 provides more background on Deep Uncertainty, and reviews both of the above methods including the DMDU paradigm.

## 3.9 LITERATURE CONCLUSIONS

After briefly summarizing the various literature streams, we further explore their potential to offer specific improvements to national DIP practices.

### 3.9.1 Literature Overview

The sections of this chapter provide an overview of the principal streams of academic literature that contribute to the core of this study and provide interesting insights to the DIP problem. The financial literature reveals both the discounted value of money over time, and the information value of waiting to invest which may reduce information uncertainty and the risk of bad investments. The operational research literature provides mixed integer programming methods that can efficiently optimize portfolios where benefit can be fully and validly modelled. The NATO SAS literature treats acquisition processes and risks, lifecycle costing, the design and test of long-term planning processes through to portfolio design, offers tools to evaluate risk in strategic planning and other areas to bring insight into unstructured problems. The Systems Analysis (SA) literature builds decision support approaches around the vital connections between purpose and choices with analysis that clarifies consequences and risks, enabling problem owners to make military cost-benefit judgements with more confidence. Decision Analysis brings specific approaches to the management of every type of decision complexity including that of modelling benefit before introducing simplification for efficient computation. From Decision Analysis come awareness of and vigilance for the many forms of bias, and the Decision Quality construct that efficiently encapsulates the span and perspectives of Decision Analysis to reveal biases and manage other aspects that can derail a decision. It also furnishes two decision process ideals, Decision Conferencing, and the Dialog Decision Process, capable of improving decision quality and customizable to address a broad range of difficult challenges. Decision Making under Deep Uncertainty tackles the future's unbounded power to surprise decomposing scenarios into assumptions that can structure the future to test decision alternatives against the foreseeable future in aggregate.

### 3.9.2 Decision Quality

Each stream of literature makes a distinct contribution to the DIP problem. The DA perspective reminds us not to rush to compute solutions before we fully explore the true requirements of the final decision. The DQ framework compactly distils the DA orientation into a rich, executive-level approach in a way that resonates distinctly with the SA literature's consistent focus on consequences: intended, expected and uncertain. To illustrate this, we repeat Fisher's 1970 summary of SA [20] in Section 3.4, interspersed here with the numbered dimensions[3] of DQ in square-brackets:

> *Systems analysis may be defined as inquiry to assist decisionmakers in choosing preferred future courses of action* **[6. commitment to action]** *by (1) systematically examining and re-examining the relevant objectives* **[1. an appropriate frame]** *and the alternative policies or strategies for achieving them* **[2. Creative and feasible alternatives]***; and (2) comparing quantitatively where possible* **[3. Values and trade-offs]** *the economic costs, effectiveness (benefits), and risks of the alternatives* **[4. Relevant and reliable information]**.
>
> *It is more a research strategy than a method or technique; and in its present state of development, it is more an art than a science* **[both true of judgement-based Decision Quality]***, although scientific methods are utilized wherever possible* **[5. Sound Reasoning]**. *In sum, systems analysis may be viewed as an approach to, or way of looking at, complex problems of choice, usually under conditions of uncertainty.*

The harmony between SA and DQ is reinforced with a similar treatment of Enthoven's six tenets of SA [21] and Davis's further three tenets [22]:

1) Decisions should be based on explicit criteria of national interest, not on compromises among institutional forces. **[1. an appropriate frame]**
2) Needs and costs should be considered simultaneously. **[3. Clear values and trade-offs, 5. Sound reasoning]**
3) Major decisions should be made by choices among explicit, balanced, feasible alternatives. **[2. creative and feasible alternatives]**
4) The Secretary of Defence should have an active analytic staff to provide him with relevant data and unbiased perspectives. **[4. relevant and reliable information]**
5) A multiyear force and financial plan should project the consequences of present decisions into the future. **[supporting 5. sound reasoning]**
6) Open and explicit analysis **[5. Sound reasoning]** (including transparent data and assumptions **[4. Relevant and reliable information]**), available to all parties **[generating 6. commitment to action]**, should form the basis for major decisions.
7) Decisions should confront "deep" uncertainty and disagreement **[4. relevant and reliable information]**
8) The planning process should ensure creative **[2. creative and feasible alternatives]** and effective collaboration across strategy, operations, technology, programs, and budgets. **[6. commitment to a decision]**
9) The planning process should provide for monitoring, feedback, and adaptation. **[6. commitment to action]**

[3] Note that this study has introduced DQ dimensions in a different order from that of its originators. We have put Values and Trade-offs before Information, but Spetzler et al. (2016) [31] and others put it after Information. Since it is not a procedure, it should not matter.

We note that the six dimensions of the DQ framework appear to be more general and succinctly elaborated than the nine tenets of SA, which seem to be contained within DQ's six dimensions. The DQ framework is also completely scalable from slightly challenging all the way to grave and deeply complex and applicable to a wide range of difficult decisions in contexts beyond those of capital investment resource allocation, having been shown to improve the decision-making culture of entire organizations [31], [38].

The next chapter reviews the development, administration, and analysis of a survey of national DIP practice.

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# Chapter 4 – A SURVEY OF NATIONAL PRACTICE

The literature dealing specifically with DIP contains many descriptions of what nations and militaries can do and have done, but also prescribes what they should do, which is the focus of this investigation. We wanted to also discover what we could about how nations currently make DIP decisions. However, the sensitivity of the subject makes this discovery challenging and limits the extent of information available. The security imperative surrounding strategic National Defence (ND) judgements, and the political downside potential of exposing strategic resource allocation details to an unclassified international audience, led us to expect relatively little sharing between nations toward adopting internationally common approaches. It would also limit our capture of the details of national context that make one approach more suitable than another. Hence, this may be considered an initial foray into perhaps the most consequential and least explored aspect of defence planning within the NATO SAS literature[1].

Section 4.1 describes the design and execution of the survey. In Section 4.2, we report the most significant results of the survey organized according to the six dimensions of the Decision Quality construct (also see Section 4.3: Reports Survey Conclusions and Limitations). The survey questionnaire was structured in 10 topically-organized spreadsheets. A detailed analysis of results from each spreadsheet topic can be found in Annex C. The actual questionnaire appears in Annex D.

## 4.1 SURVEY DESIGN AND EXECUTION

Under the circumstances it appeared that an anonymous survey soliciting general parameters of the problem and any instances of the use of any recommended practices found in the literature in national DIP decisions, whether military or civilian, executive, or supporting analyst, could reveal trends and valuable comments on specific issues. Accordingly, the survey was developed and administered with the aim of exploring the DIP process of Allied and PfP nations, and the extent to which nations applied concepts, tools and/or approaches recommended in the literature[2]. The topics addressed in the survey included: investment planning time frames and processes, how preferences and end goals/objectives are considered, which benefit modelling methods are used to facilitate portfolio decisions, what cost categories and resource constraints are considered, and how complex investment interactions and risks are addressed.

The survey was designed under the assumption there is one specific approach each nation applies in its DIP process, and that only those involved and therefore knowledgeable can serve as respondents. Because of this, only a single response was solicited from each nation. The credibility of the survey results therefore critically depends on the qualifications of the responding experts. We sought respondents that had been involved in the past five years in making or providing analytical support to cost-informed decisions prioritizing defence capital investments intended to deliver, among other things, major military capital equipment. As the questions covered a broad range of topics, the instructions recommended as an ideal that the survey be completed by a small team with experience in both investment prioritization decision processes and the supporting analyses.

In September 2019 two nations responded to a pilot version of the survey, providing feedback on the clarity of the questions and time required to complete the survey. Based on these results, some modifications were made for the final survey, and responses updated by those who had initially responded. The final survey included 105 questions. The response menus used in the survey, depending on the question, were principally Likert-type scales with some yes/no items and some use of custom ordinal scales. (See the final survey questionnaire presented in Annex D.) Each question also included a free text field for comments. Besides assuming the respondent had good knowledge of English, we also made some assumptions about respondent

[1] The material presented in this chapter is also reported in Ref. [1].

[2] A principal source for the survey questionnaire was the work of Tate and Thompson [2], [3].

familiarity with analytical terms (e.g., decision trees) and some process terms (e.g., decision conferencing), some of which would be less familiar outside English-speaking countries. A glossary was included in case technical terms were significantly different from more familiar terms in the respondent's native language.

The survey was delivered as a MicroSoft Excel® workbook with conditional formatting that highlighted missing responses along with an accompanying PDF file that some respondents preferred to print out, write in, scan and return. National experts were contacted through the professional networks of task group members and at the request of the SAS Panel. A letter asking nations to participate was also provided by the head of NATO STO. Between February 2019 and June 2020, responses were received from a total of 13 nations within NATO and its wider community. With only a few minor exceptions, surveys were filled in completely. Each country also provided at least some comments; a total of 433 comments were received that enhanced interpretation of the responses, sometimes pointing out questions that were difficult or not meaningful for some countries to answer.

Anonymity of respondents and their nations was promised, and both are concealed in the results presented here. However, if we define a large nation as having more than 20 million inhabitants and Gross Domestic Product of at least 1000 billion USD, then six responding nations were large and seven small. In terms of specific affiliations, eight survey respondents represented MoDs, three military forces, and two research institutes that supported DIP decision making. Some of the diversity observed in the responses may reflect differences in the roles and responsibilities of these organizations in the DIP decision process.

## 4.2 SURVEY RESULT AND ANALYSIS

### 4.2.1 An Appropriate Portfolio Decision Frame

Decision framing concerns defining the boundaries or scope of the portfolio problem. This requires scoping that is aware of decisions already taken that will constrain the new Planned Investment Portfolio (PIP), and recognizes any decisions to be taken later, so that the matters to be settled in the portfolio review are clear. Thus, the frame determines which portfolio elements are and are not subject to review. The frame includes the intended outcomes the investments in question must serve (Ends), the resources and time constraints imposed on them (Means), and the varieties of investments the PIP could include (Ways). Topics addressed in the survey under Framing included the time period covered by the portfolio and relevant sub-periods, the variety of cost categories included in the portfolio budget, other resource allocation decisions taken during the decision process, and the extent to which portfolio intent (goals/objectives) is articulated.

The various PIP durations reported in the survey data ranged from three to twenty years, divided into between one to five sub-periods. The reported intervals between PIP reviews ranged from annually, to every six years. Countries most frequently adopt rolling multi-year plans which are revised each time a PIP review is conducted. The collection of respondent comments emphasized three PIP sub-periods. The first sub-period often consisted of building the following year's defence budget, which involves detailed costing for the next fiscal year, and multi-year funding forecasts. The second PIP sub-period includes a Preparation period ranging from 2 to 4 years where cost estimates are less certain and involve acquisition planning that may include revisions of Defence Plans. The third sub-period focuses on the most expensive and risky Investments, Research and Development (R&D) and Acquisition, again requiring revisions of Defence Plans. With large differences in PIP duration between nations, there are corresponding differences in the issues confronted in portfolio reviews. For example, if a PIP stretches only a few years into the future, reviews tend to focus on more mature projects with more reliable cost estimates than may be the case for planned investments further in the future (e.g., 10 years or more).

The survey asked which of twelve cost categories nations include in their PIP budgets. The cost categories, in descending order of frequency of responses, were purchase/acquisition costs, Information Technology (IT) systems, R&D, transport cost required for the investment, project management, facilities, mid-life update, annual operating costs, operator training, transition costs (e.g., new tactics), end-of-life costs, and personnel costs.

All thirteen respondents included defence acquisition (the purchase of new systems) in their DIP decisions. Only two nations did not include R&D costs, but their accompanying comments suggest some equipment is purchased "off-the-shelf" so that R&D costs may already be incorporated in the purchase price. Only seven respondents indicated they include future operating costs in their PIP budget estimates. Since PIP time frames are generally shorter than the expected operational life of new systems, it is not surprising only four nations factor disposal (End-of-Life) costs/benefits in their PIP estimates.

Figure 4-1 shows that PIP reviews often consider and revise types of defence resource allocation other than major equipment acquisitions within the same decision process. Corresponding to the concept of investment in a "Total System," roughly half of the nations included force size considerations in their PIP process.

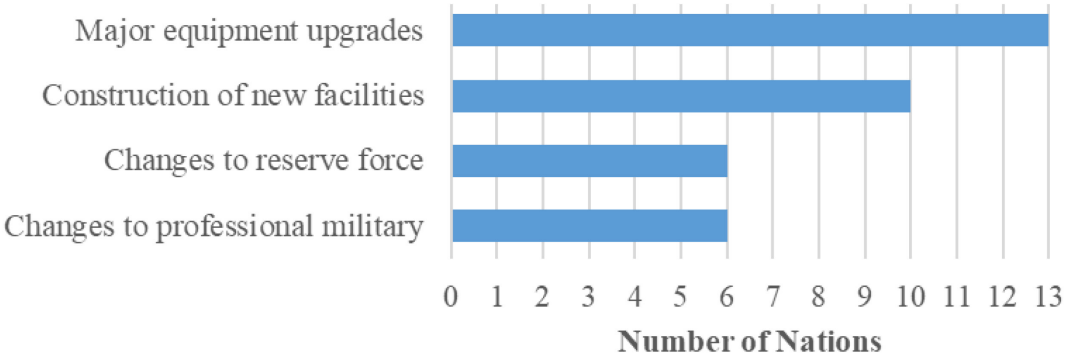


**Figure 4-1: Other Allocations Prioritized with Capital Investments.**

In Figure 4-2, Figure 4-3, Figure 4-4, Figure 4-5, lighter and darker green bars to the right indicate the number of respondents tending to agree or strongly agreeing, respectively, with survey statements of national practice. Yellow bars near the centre indicate neither agreeing nor disagreeing. Orange and red bars to the left indicate those tending to disagree or strongly disagreeing with the statement. Left-most grey bars indicate non-Likert-type responses.

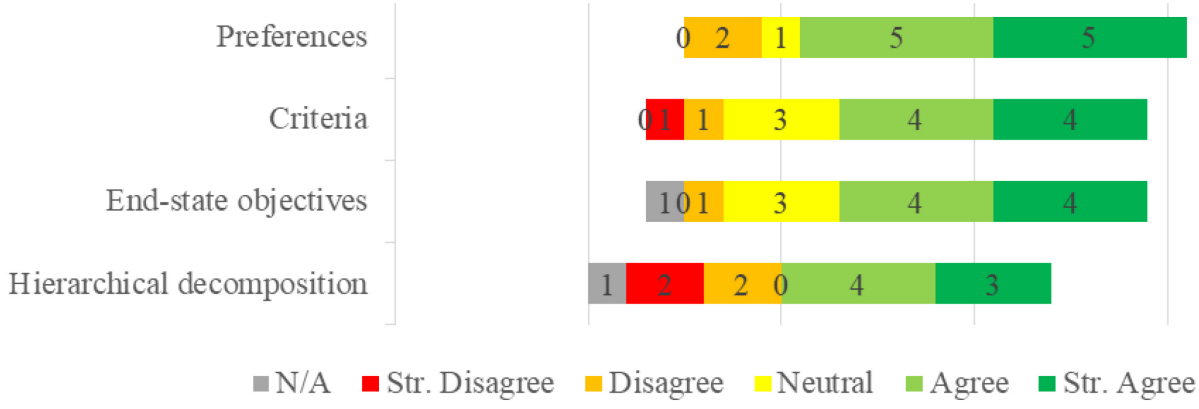


**Figure 4-2: Formal Articulation of Intent for the PIP.**

Figure 4-2 shows the extent to which nations articulate intentions for their PIP at the portfolio level. Ten countries indicate that preferences and priorities are solicited from PIP decision makers and participating stakeholders. Eight indicate that they develop portfolio criteria, that they are stated as end-state objectives, and seven that objectives are hierarchically decomposed into sub-objectives. While appreciation is evident among respondents for the utility of developing and applying detailed and comprehensive portfolio objectives in terms that can be measured, accompanying comments reveal multiple challenges in fully implementing this approach.

Out of thirteen different resources whose limitations can undermine the realization of investment benefits (see list in Annex C, Appendix C.9), only investment funding and operating budgets were formally modelled as constraints in the PIP decision process, by nine and five countries respectively. To the extent other limitations were considered, they were discussed, but not formally modelled. Facilities (9 nations), project management resources (8 nations), and training (8 nations) were the limited resources most often considered in PIP decisions.

### 4.2.2 Creative and Feasible Portfolio Alternatives

Identifying strong candidate portfolios requires ensuring that the full range of investment options that could be included in the revised portfolio is clearly identified and each investment undergoes categorization as necessary to track portfolio balance criteria [3]. Then, the variety of feasible investment combinations can be properly explored and evaluated.

Topics explored by the survey related to the variety of portfolios considered included whether nations explored how well each portfolio objective could be served and whether the investment inventory was limited by too few investments contributing toward their achievement, called “under-served objectives”, and whether such objectives with weak achievement potential were subsequently fortified by developing additional investment options[4]. Figure 4-3 shows national responses to statements that they connect contributions from all investment options to each PIP benefit criterion, that they identify under-served PIP benefit criteria, and that they identify potential new investment options that better support under-served PIP criteria.

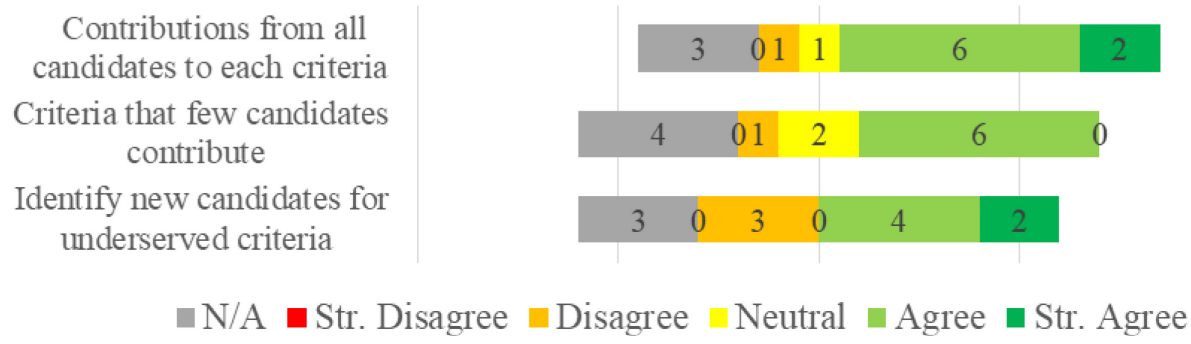


**Figure 4-3: Creating New Investment Options.**

Four respondents indicated their country did not explicitly use PIP benefit criteria. However, Figure 4-3 shows that, of those that do, all but two tended to agree that they examine how various investment options contribute to their benefit criteria. Only six respondents indicated identification of potential benefit gaps. Six respondents also indicated they actively search for new candidate investments in under-served PIP benefit

[3] See Section 5.2.2 for the role of categories in tracking the satisfaction of portfolio balance criteria.

[4] This approach to ensuring sufficient objective coverage potential is described in Keeney’s Value-Focused Thinking [4].

criteria. Accompanying comments by several countries describe processes where capabilities and capability gaps are seriously considered, but not always explicitly in terms of any proposed mapping of investments to a well-defined set of benefit criteria.

### 4.2.3 Clear Portfolio Values and Trade-Offs

Coherent portfolio evaluation is helped by developing explicit portfolio preferences and priorities between competing portfolio criteria. If stated in quantitative terms, these values and trade-offs reduce the complexity of portfolio evaluation. Some survey questions were designed to reveal the extent to which nations use quantitative versus qualitative approaches. They addressed the use of metrics to track levels of different types of portfolio benefit, metric interpretation in terms of measurable value and weighted sum aggregation of overall values. Figure 4-4 indicates that seven nations agreed that they develop and use metrics that measure the extent to which a portfolio satisfies PIP criteria, but the accompanying comments suggest quantitative metrics mostly relate to constraints on the PIP, including available resources (personnel, etc.) and budget limits.

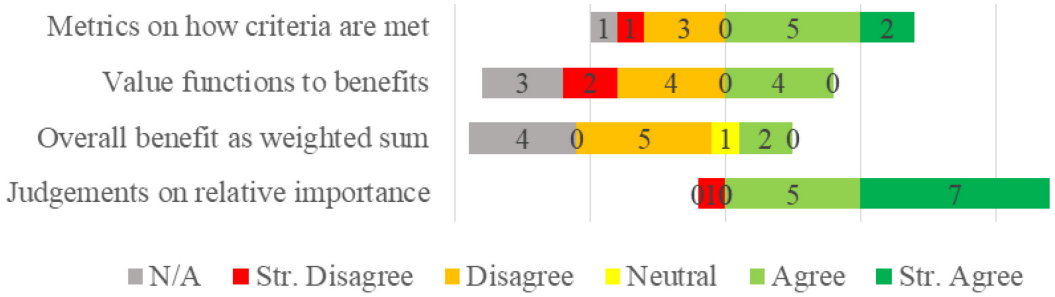


**Figure 4-4: Approaches for Evaluating Performance of Alternative Portfolios.**

The figure also suggests that, if anything, most nations model benefit in more qualitative terms. All but one nation agreed they ask decision makers and participating stakeholders for their judgments regarding the relative importance of different types of benefits promised by portfolios. While four nations tend to agree that they translate metric scores into relative amounts of value, and two somewhat agree that they aggregate these for overall value as a weighted sum, clarifying comments refer to project-level use rather than for portfolio-level criteria[5].

The survey presented respondents with sixteen different phrases referring to possible benefit modelling approaches and techniques from the literature (see list in Appendix C.4). The survey queried the extent to which these are used by nations to model the benefit expected from a particular portfolio. Eight out of 12 countries reported at least one item as being either “directly related” or “used” by that country in its portfolio evaluation. Only four benefit modelling approaches were selected as either “directly related” or used by more than one country:

- Priority lists (1 used, 3 directly related)
- Multi-Criteria Decision Making (0 used, 4 directly related)
- Requirements management (2 used, 0 directly related)
- Additive value (1 used, 1 directly related)

[5] This tends to negate a marginally significant result for this data: on the hypothesis that large nations use more quantitative benefit modelling than small ones, a Mann-Whitney test on levels of agreement produced a value of p = 0.049.

Respondents could indicate unfamiliarity with an approach, and 20 such responses were recorded, 15 of which came from two nations.

### 4.2.4 Relevant and Reliable Portfolio Information

High quality portfolio decisions require information of known origins, fitness for purpose and accuracy. Specific attention to these attributes facilitates appropriate treatment of conflicting information and provides an appreciation of information reliability. For example, risk management must confront information uncertainty and the risks of relying on uncertain information when making defence investment decisions. An important tool is specifying information ranges (confidence intervals) instead of point estimates, which tend to conceal unstated assumptions. Questions in the survey related to information quality addressed the use of ranges (interval estimates) in cost data and the explicit treatment of various types of portfolio risks.

Nations were asked whether they specify different types of investment cost as a single number (point estimate) or as a probable cost range. Of the responses that specified the treatment per type of expense/cost, half indicated use of point estimates and half the use of cost ranges. This proportion persisted in both large and small nations. That said, respondents only provided "point-or-range" responses for 44% of the types of expenses, with smaller nations leaving blanks for about a third of the queries, and larger nations leaving 80% blank[6].

Risk assessment approaches (e.g., Refs. [5], [6]) in the literature typically address four questions:

1) What can go wrong?
2) What is the likelihood/probability?
3) What are the consequences? and
4) What can be done to mitigate the risk?

In evaluating individual investment options, there are three main concerns: Cost, Schedule, and Performance. An investment may cost more than estimated (cost); deliverables might become available later than expected (schedule); and it might deliver less benefit than required (performance). Figure 4-5 shows responses to statements that specific risk types are modelled at the investment level as well as the risk of portfolio funding being lower than expected. Cost risks are modelled more often than other risks. Accompanying comments noted that a variety of risks are discussed in nations' DIP decision processes that are generally not explicitly modelled, nor assigned specific probabilities to assess their likelihood. Comments also indicate that nations that do not model specific risk types still engage in contingency planning.

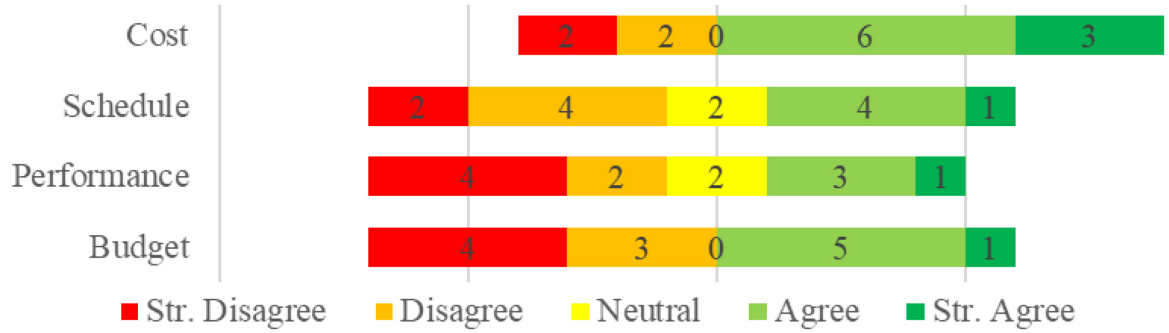


**Figure 4-5: Investment-level Risk Modelling Responses.**

[6] Three of six larger nations provided no "point-or-range" responses at all.

### 4.2.5 Sound Portfolio Analysis

Sound portfolio analysis reveals the costs, benefits and risks associated with alternative portfolios. It applies information of known quality to the evaluation of portfolio alternatives according to explicit portfolio values and trade-offs anchored in portfolio-level objectives. Risks include portfolio robustness in the face of future uncertainty in capability needs and portfolio execution outcomes and the sensitivity of portfolio evaluations to information quality and value judgements.

Survey questions addressing aspects of portfolio analysis touched on the use of portfolio optimization software[7] and treatment of interactions between benefits delivered by different investments.

The application of optimization software was reported by four larger and four smaller nations. However, there appeared to be little correspondence between these responses and their use of portfolio effectiveness criteria or metrics as one might expect to model the benefit portion of the cost-benefit ratio that optimization software generally seeks to optimize.

Questions explore how nations treat various kinds of interactions between investments. Interactions explored include: complements – deliverables whose benefit is only realized through assets delivered by one or more other investment; substitutes – investments capable of satisfying the same requirement; positive externalities – another investment partially filling a related requirement so that the marginal benefit of investing to fully satisfy the requirement is less than without the other investment; synergies—investments delivering more benefit in combination than the sum of their individual benefits separately; and linked investment risks – materialization of a risk simultaneously affecting multiple related investments[8].

Figure 4-6 reveals that the investment interactions most often treated systematically are substitute investments[9], which are constrained, followed by complements that two nations constrain to include needed contributing investments and two others that define acceptable combinations of complementary investments. Treatment of externalities, synergies, and other interactions (not explicitly specified by the respondent) are dealt with systematically by a couple of nations. The most common approach to investment interactions that nations indicated was merely to note the interaction in discussions and to adjust the planned investment portfolio accordingly. Other nations apparently disregard several possible investment interactions. There appeared to be no significant difference in the treatment of investment interactions by large and small nations.

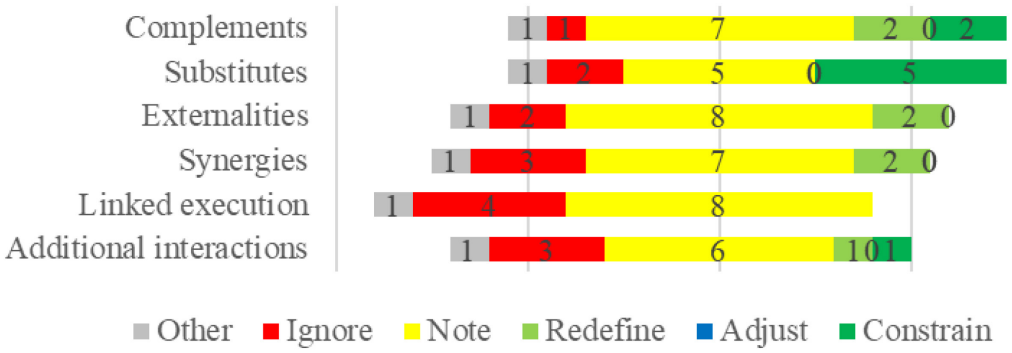


**Figure 4-6: Modelling Alternative Investment Interactions.**

[7] Note that optimization software is generally used to construct portfolios that will have a somehow optimal evaluation, arguably putting the use of such software in the categories of creative and feasible alternative portfolios. It is treated under portfolio analysis in this and the next chapter because of its dependence on portfolio information and values and trade-offs implicit in the objective function to be optimized and for a more sequential presentation of material.

[8] For more on investment value interactions, see Section 5.4.4 on interaction information and Section 5.5.4 on interaction modelling.

[9] Comments indicate that the constraint is to limit investment selection to no more than one investment per requirement.

While comments indicate that respondents generally consider investment interactions to be important in the DIP process, they note the difficulty of capturing all the complexities and rely on the most significant interactions emerging naturally in portfolio discussions.

### 4.2.6 Commitment to a Portfolio

Successful implementation of a portfolio decision depends upon broad stakeholder confidence in the decision. This, in turn, depends on three important factors. First, stakeholders need to know their input has shaped the decision. Second, the decision process needs to earn the confidence of stakeholders that it has adequately addressed the challenges to making a good decision. This is addressed directly when stakeholders participate in explicit evaluation of decision quality, requiring allocation of the necessary time. Finally, implementers need an operational plan that explicitly addresses portfolio risk management priorities.

Survey questions touching portfolio commitment asked about approaches used in the decision process. These include: the Dialog Decision Process – a sequence of meetings between a decision board and an analysis team, together executing defined stages in the portfolio review process; Decision Conferencing – a skilled neutral facilitator leads decision makers and key stakeholders through portfolio review; and Consensus Modelling – tools aiding negotiation toward consensus by showing the degree and character of stakeholder agreement or disagreement. The responses reveal some inconsistency suggesting respondents may not have been familiar with these terms or approaches.

Ten nations reported using a Dialog Decision Process (DDP); only three smaller nations did not indicate its use. Of these, six reported stable membership of decision boards, three reported formally defined roles for both board and analysis team members in each stage of the meeting sequence, and four reported the portfolio decision process to be a standard process for making strategic decisions across defence. None reported that any specific training was provided for board and team members in their roles at each decision stage.

Six nations reported using Decision Conferencing, including two larger nations. Three of the six also use DDP. All six reported developing portfolio benefit criteria during the process. Three reported professional facilitation of the meetings, and two reported continual display of results as DIP discussions progress. Two reported the attendance of lawmakers at decision conferences, and one the attendance of others suitably cleared, but with no specific role in Defence. Three smaller nations reported the use of consensus modelling with no further elaboration.

## 4.3 SURVEY CONCLUSIONS AND LIMITATIONS

The survey shows that every responding nation had a planned investment portfolio that included major capital equipment, most often constrained by funding and often by other available resources. All were able to describe the stages involved in drafting and approving their PIPs, and each nation's process was distinct. The most commonly reported decision process used was the Dialog Decision Process.

All but one nation elicits judgments regarding the relative importance of different criteria from its decision makers and participating stakeholders. Ten nations solicit preferences and priorities from PIP decision makers. Comments by several nations describe discussions of capabilities and gaps without explicitly mapping alternative portfolios to see how well they satisfy a well-defined set of benefit criteria. Whereas most nations attempt to capture alternative portfolio benefits qualitatively, larger nations may employ more quantitative benefit modelling.

Nations differed in the extent of their elaboration of portfolio-level intent (goals/objectives), and the extent to which they developed hierarchical decompositions of objectives and sub-objectives. In terms of investment interactions, a minority of countries treat investment substitutes systematically. Instead, most nations simply

note these and other interactions in their discussions and adjust their portfolios accordingly. The nations were also divided with respect to adjusting force sizes while prioritizing defence investments, recognizing the implications for the "Total System Cost" of a planned investment portfolio.

Of the sixteen benefit modelling approaches surveyed, only Priority Lists, MCDA, Requirements Management and Additive Value were reported as either used or directly related to approaches used by more than one nation. More than half of the surveyed nations listed at least one of the 16 approaches listed as either used or directly related to their approach. Most nations differed in their treatment of investment risks, with comments revealing many nations do not model risks explicitly, nor assign specific probabilities but merely discuss the variety of risks in their DIP decision process.

The survey data indicates that most portfolio benefit-maximizing strategies tend to be ad hoc, not relying on formal modelling or algorithmic/mathematical support. A related trend seen throughout the survey is that response distributions, both shown here and those excluded from the chapter for brevity, show greater agreement with statements about early steps (defining objectives, mapping investments to objectives, examining investment risk) and shift toward disagreement with statements about more advanced steps (such as defining and aggregating value functions, developing new investments for under-served objectives, evaluating portfolio risk). This is in line with how few nations reported using named benefit modelling techniques in their portfolio analyses. The abundant alternative computational techniques proposed in the literature show limited use in real DIP decisions. Perhaps this is to be expected given the literature rarely acknowledges the full extent of political and other complexities that impact DIP decisions.

Beyond these trends, the dominant observation is how varied national practices appear to be. Procedures vary widely between nations for natural enough reasons, having been shaped by distinct cultures, histories, and governance philosophies. It appears each nation has an opportunity to learn from others given the rich diversity of approaches to DIP.

These observations also confirm the need for investment prioritization guidance to be principles-based rather than recommending specific procedures. While the complexity of DIP decisions is at least partly computational, the challenges of uncertain future needs, complex benefit realization, limited control over costs and the dynamics of public accountability introduce most of the difficulty of DIP. It is in this light that the Decision Quality construct may be most useful, specifically applied to managing investment selection and prioritization, which is why survey result highlights are structured accordingly in this chapter. The next chapter documents efforts to assemble principle-based guidance applicable to DIP decisions across NATO and partner nations.

## 4.4 REFERENCES

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[2] Tate, D.M. and Thompson, P.M. (2016). Portfolio selection and resource allocation for defence applications. Institute for Defence Analyses, IDA Document NS D-5439, March 2016.

[3] Tate, D.M. and Thompson, P.M. (2017). Portfolio selection challenges in defence applications, institute for defence analyses. IDA Document NS D-8493, August 2017. https://www.ida.org/research-and-publications/publications/all/p/po/portfolio-selection-challenges-in-defense-applications

[4] Keeney, R.L. (1992). Value-Focused Thinking: A Path to Creative Decisionmaking, Harvard University Press: Cambridge, Massachusetts.

[5] ISO 31000 (2018). Risk Management – Guidelines.

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# Chapter 5 – DEFENCE INVESTMENT PORTFOLIO DECISION QUALITY

This chapter offers guidance that may be useful to nations in identifying defence capital investment portfolios best able to deliver desired long-term national outcomes. It applies the six dimensions of Decision Quality (DQ) introduced in Chapter 3 and used to structure survey results in Chapter 4, to help tackle the Defence Investment Prioritization (DIP) problem outlined in Chapter 1. The DQ approach provides a structure that enables the Decision Maker (DM)[1] to monitor and manage progress in any decision process and to make balanced judgements regarding whether improvement is still worth pursuing before committing to any difficult decision. In effect, DQ introduces its own portfolio of six types of achievement needed as a foundation for a strong decision. It helps orient DMs in making affordable trade-offs between allocations of decision process time and effort before committing to a course of action.

The DQ framework also provides a perspective from which to view past DIP experiences, enabling retrospective estimates of past decision quality and affording opportunities to consider the degree of benefit to be expected by choosing to implement advice such as that provided in this report. As with a Planned Investment Portfolio (PIP), adjustments in decision processes should only be undertaken if they are expected to lead to better outcomes through better decisions given the time and money available to reach a decision.

As noted in Appendix B.6, which introduces DQ in detail, the structure of this chapter is not to be interpreted as recommending a sequential six-step procedure, even though sequential relationships may exist between its elements.[2] Rather, it presents six dimensions present in every decision, each of which need to be addressed sufficiently if a decision is to be implemented as intended and advance the outcomes desired. Each dimension offers a valuable perspective through which defence organizations can view and evaluate their own portfolio decision processes. This offers nations an opportunity to adjust their decision processes in ways that are simultaneously suitable to their own context and better able to achieve high quality decisions.

This approach is not meant to be prescriptive but is offered to expand the menu of analysis alternatives available to DMs and those providing decision support. Discussion questions are provided to draw out the strengths and weaknesses of progress within each DQ dimension to aid DM's assessments of whether it is good enough to reach a high quality decision. The questions suggested for discussion, and the notional descriptions anchoring different decision quality ratings for each dimension, are offered not to provide a standard for nations to meet, but, rather, to illustrate what quality means more clearly in each DQ dimension. The questions also suggest features that should emerge as quality levels rise and clarify necessary judgements about the desirability of improvement along each dimension. This allows the DM to set and adjust appropriate DQ goals for each dimension, to call for more work on those where improvement is feasible and required, and to be more confident in their decision when all refined DQ goals have been attained. The standards set in each nation will be informed by time and resources made available to revise the portfolio, other decisions waiting to be made, and the DM's risk appetite.[3]

[1] Of course, the authority ultimately deciding to go ahead with any investment is the government; all others merely inform and recommend. For our purposes, the DM is the executive (civilian or military general/flag officer) who must select a portfolio and defend it when seeking any necessary higher governmental approvals.

[2] Specific and proven guidance on sequencing defence investment portfolio decisions is available throughout the literature. Our best process advice is in Appendix B.8 on the Dialogue Decision Process, but other tried and proven processes are offered in the literature, including Phillips [1], Burk and Parnell [2], Tate and Thompson [3], [4], Cree and Bossley [5] and Davis [6].

[3] Note that this chapter presumes familiarity with the more detailed treatment of Decision Quality offered in Appendix B.6.

## 5.1 AN APPROPRIATE PORTFOLIO DECISION FRAME

The framing of the portfolio decision defines what is needed and desired from the decision: the broader strategy it should serve, its intent, its scope, its constraints, and the resources available to reach it. In particular, the frame includes decision boundaries and constraints on the decision process prior to involving the key stakeholders. These are considered as prior or "external" to the main decision process, while other features of the required decision which are considered "internal" require the decision process to advance further before they can be fully defined.

### 5.1.1 External Frame Elements

External frame elements include the national strategic context and the corresponding requirements it imposes on DIP decisions, the scope of the decision, the time, and resources available to reach a decision, and its governance context. The national strategic context includes the roles, tasks or goals and objectives that the government has assigned to National Defence (ND) to defend and advance national interests, especially those interests deemed vital to the well-being of the country. This context informs Defence policy and strategic defence objectives and will imply investment priorities necessary for the military to succeed in its roles. As discussed in Section 2.2 and explained further in Appendix A.2, topics that may be addressed include national grand strategy and implementing policy, international competitors, strategic partnerships such as membership in NATO and other alliances, national industry concerns, and technological developments.[4]

The external frame should include plausible future challenges to national interests, the selected national grand strategy, corresponding defence strategy and policy, and the implications for military capabilities and those of other related or interacting levers of national power. It will include policy objectives whose attainment will depend in part on the future state of ND assets to be upgraded or acquired through investments within the scope of the portfolio decision. These objectives will be broader than can be achieved solely by investment portfolio decisions, although they will imply objectives that the prioritization can achieve that need to be articulated during the decision process, relying also on non-materiel capability inputs: operators, force structure, doctrine and levels of training and certification, etc.

The external frame should explicitly address expectations and requests from strategic partners and alliances such as the Capability Target Package assigned to the nation by NATO. It should also specify projects to be excluded from review, whether because their priority will be determined through other processes or because their priority (either inside or outside the PIP) is not in question. The scope includes current and projected portfolio investment funding, and any other limited resources that the decision needs to allocate (e.g., staff effort), but not already committed or that will be committed through other decision processes. Budget constraints may only be approximate at the start of the decision process but should stipulate a range of possible funding levels and relevant criteria for how they will be determined.

Defence often accounts for a large share of a government's capital investments. Governments need to be deliberate in the signals they send to industry regarding long-term investment plans so that strategic domestic sectors have the lead time necessary to prepare a competitive variety of investment options by the time the government is ready to solicit investment proposals. Sudden and large changes in investment priorities can be economically disruptive and may jeopardize an administration's political narrative and, in turn, the government's confidence in ND strategic planning and management. Hence, the prioritization frame should recognize practical limits on the extent of changes to previous investment plans that may be politically and economically acceptable.

The decision's governance context includes identifying decision makers, ideally a single point of accountability for reaching and documenting a decision and any offices necessarily involved in generating

[4] See Appendix A.2 "Policy Underpinnings to Defence Investment Prioritization" for more detail.

the decision or supporting the decision process, as well as those accountable for follow-on decisions. It should also acknowledge the potential for offices/stakeholders not participating or represented in the current decision process to subsequently require modifications to the decision before it is implemented.

The strategic context, intent, decision scope, resource constraints, and governance context are all examples of external decision frame elements, anchored in authorities mostly outside the discretion of ND. These elements external to the formal decision process may be usefully communicated in a Terms of Reference document at the beginning of the decision process, which may also include internal elements listed below.

### 5.1.2 Internal Frame Elements

Internal frame elements are developed by applying defence-specific expertise to the external frame elements to bring structure to the portfolio option space, including the inventory of in-scope investments. External frame elements need to be translated into specific combinations of attributes desired from the portfolio of investments over time, including more fully elaborated goals/objectives and any financial or other resource constraints. These correspond to the identification of Ends (outcomes for combined investments to achieve), Ways (classes of investment options to be considered in a revised portfolio) and Means (resources specifically available to support investment execution through to delivery).[5]

#### 5.1.2.1 Investment "Ends"

Stated portfolio intent helps to define the outcomes desired from investment execution ("Ends"). These outcomes become objectives to be achieved through combinations of defence investments and are developed as practical implications of external frame elements through defence-specific expertise to be leveraged in the decision process. Clear investment objectives most powerfully advance the prioritization context when expressed as "fundamental objectives"[6] (mentioned in Section 3.4), which decompose into measurable sub-objectives. Ideally, these are defined attainments that can be recognized objectively or at least be assessed meaningfully by experts or decision makers. The process of developing explicit fundamental objectives can drive a collective learning process that gets decision makers and stakeholders working from a set of shared assumptions. Figure 5-1 illustrates such a hierarchy descending from one fundamental objective. Portfolio decisions must generally serve several conflicting fundamental objectives, necessitating trade-off judgements.

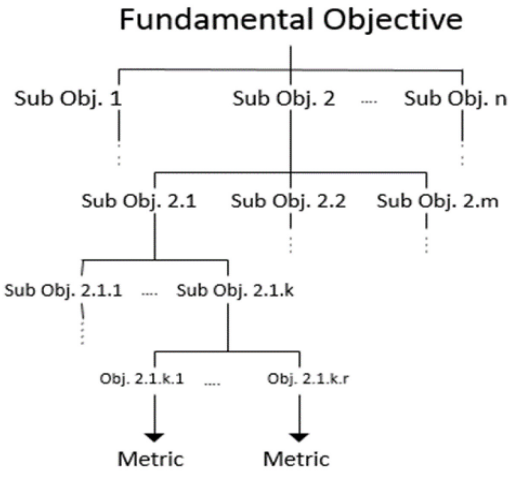


**Figure 5-1: An Objectives Hierarchy Under One Fundamental Objective with Metrics.**

[5] Recent writings (King [7]) criticize Lykke's formulation of Strategy [8], which better formulates strategic resource management.

[6] See the material on fundamental objectives in Appendix B.6, Section B.6.1.

The complexity of system interactions to achieve operational objectives and the difficulty this poses for DIP is often managed through military capability partitions defined by the effects they must achieve in different operational circumstances. If this partition is constructed as a taxonomy of capabilities, it can provide useful building blocks for both operational planning and for long-term defence planning. Using capability partitions, planning scenarios involving "pacing threats"[7] can be analysed for the combined capability levels required for mission success. This sets up benchmarks or standards against which to evaluate national military forces augmented by what different portfolios of investments promise to deliver.[8]

To the extent that ND has defined a capability partition that spans what it must be able to do to fulfil its government mandates, every change initiative motivated by a capability shortfall will map to a place in the partition. If the partition is hierarchically structured and defined in terms of operational tasks or effects, these can serve as points of reference for capability objectives, leveraging the difficult work already done in structuring military capabilities to build combinations of capability investments.

The partition also supports analysis of any partial substitutes (called positive externalities in Chapter 4), synergies or other capability interactions, particularly as they would arise in planning scenarios, so that capability value that is contingent on interoperability with other systems may inform the analysis of portfolio benefits. However, it must be acknowledged that the existence of a "perfect" partitioning scheme that is both comprehensive and composed of mutually exclusive capabilities is doubtful. With the changing character of warfighting and ever greater interconnectedness, dependencies will exist across any partitioning framework. Hence, decision makers may need to use an iterative and adaptive approach that focuses on key force dependencies and packages needed to deliver effects and identify outliers later in a force coherency analysis.

On the institutional side, hierarchical program structures where performance management has been implemented can help define fundamental objectives and measurable sub-objectives where defence program success depends upon capital assets that need periodic renewal to achieve program outcomes. Well-formulated performance management frameworks provide ready measures of program attainment that lead to measurable sub-objectives to inform capital investment decisions. Program performance metrics that are well aligned with desired program outcomes may readily imply measurable sub-objectives, indicating ways to quantify outcomes to be achieved by groups of related programs that depend on capital assets. Expected deliverable impact on well-formulated performance metrics readily translates into measurable desired investment benefits.[9] The SAS-096 Part I technical report [9] addresses this context with a causally-linked defence performance management framework at the strategic level.

In the absence of pre-existing program or capability frameworks that provide a head start on identifying fundamental investment objectives, these can be developed and elaborated into measurable sub-objectives through a process of expansion, analysis, and contraction. The expansion begins by developing a rich set of objectives covering the full intent of in-scope investments, ideally expressed as a spanning set of desired investment outcomes. Chapter 3 of Keeney's Value-Focused Thinking [10] offers a variety of techniques for generating and expanding the set of desired outcomes until they are sufficiently comprehensive, as do Marttunen et al. [11] and the NATO Alternatives Analysis Handbook [12] in the creative techniques in Part 2. The products of expansion can then be subjected to expert analysis to

[7] A pacing threat is a composite level of adversarial capability that forces may encounter, developed by rigorous analysis of the details of military capabilities being developed globally, as a comparative standard for national military force development.

[8] It follows that planning scenarios and military capability partitions should be evaluated for the extent to which they bring relevance, clarity, and confidence to defence investment prioritization judgements.

[9] The use of program performance indicators to clarify the need and potential impact of investment (and any other change initiative) can incentivize program owners to better implement performance management.

identify causal (means-end) relationships[10] and hierarchical (whole-part) relationships that imply sub-objectives as components of higher level objectives. The resulting hierarchies will imply appropriate selections for fundamental objectives decomposed into measurable sub-objectives.

#### 5.1.2.2 Investment "Ways"

Very few investment needs start with no existing capability. Current capabilities being sustained provide the basis for the future force structure. A large fraction of investments is for the renewal and improvement of existing capabilities.[11] The effectiveness, operating costs, future costs, and obsolescence issues imposed by existing and new capital assets is highly relevant to DIP decisions.

Other frame elements to resolve include the range or variety of investments that will make up the inventory of available investment options. This can include not only new investments to add to the PIP but also existing investments to remove. However, this may not include the entire portfolio since funds recovered from cancelling investments already underway after deducting cancellation penalties may not sufficiently offset the political price of eliminating previously-announced national economic activity.

Defining the other end of the scope is the least mature investment options to be considered. This will partly depend on the portfolio duration and the minimum necessary level of project maturity necessary for it to begin expenditure sometime during that period. Long portfolio durations involve more notionally defined investments that make portfolio evaluation less meaningful.

Setting the scope of the decision includes determining whether the variety of investments considered includes different investment options designed to meet the same capability goal – alternative investments to satisfy the same requirement, called substitutes in Chapter 4. These are the project options that the "options analysis" step of a project lifecycle evaluates toward a preferred solution. If substitutes are excluded from the investment option space, then the decision is strictly between requirements to be funded with no consideration at the portfolio level of alternatives solutions per requirement. If options are included, then funding a minimal option to meet a capability goal of lower priority will leave more budget room to satisfy highest priority capability goals with better (more costly) options or additional, otherwise-unaffordable solutions for other important requirements. Some substitutes with different development or scarce resource uncertainties may be included at some expense to mitigate delivery or availability risk. While including substitutes in the portfolio scope introduces solution quality as a variable in the decision, it also adds to the nuance needed in benefit modelling, the data collection burden, and the combinatorial size of the alternative space to be explored in portfolio revision.

#### 5.1.2.3 Investment "Means"

Investment execution cannot generate capability without all the other necessary DOTMLPFI[12] inputs to capability. Limitations in any of these other inputs can leave investment benefit unrealized. Therefore, assumptions regarding resource constraints need to be included in the decision frame. This may call for a review of the existing and planned availability of these resources. This could include project management capacity to carry investments through to completion, research and development capacity supporting delivery,

[10] Correlating relationships, where one outcome does not directly cause another outcome but still sets up a reasonable expectation of its impending occurrence, are similar to causal relationships and should be included with them principally because they are not hierarchical or whole-part relationships and could otherwise lead to double counting in metric-based benefit modelling.

[11] Being able to do something even much faster or much more effectively than before still constitutes improvement to an existing capability (at best, a new capability level) and not a new capability, contrary to common usage. This is an important distinction if national investment priorities are to look beyond military intent to see true investment implications for the nation's interests. The power of capabilities to clarify investment trade-offs depends upon the discipline with which abstractions are applied.

[12] Doctrine, organization, training, materiel, leadership, personnel, facilities, and interoperability.

and any limitations in other government agencies involved in investment review and approval, each subject to their own throughput and workflow constraints.

Since ND funding for defence investments may not be known at the start of the process, it may be necessary to update defence investment portfolios at different possible budget levels. Given a particular investment budget, the best resource- and risk-informed and otherwise frame-compliant defence portfolio may still deliver unacceptably low levels of future defence capability, indicating a need for adjustments in the external frame: requiring increased funding or other resources, assuming greater risk, or adjusting the national strategy. In any case, the frame may need to undergo revisions over the course of the decision process to adjust the terms on which final decision quality will be measured.

When investment need is great and budgets are constrained, courses of action that will make additional resources available for investment become relevant. For example, the opportunity cost of renewing a legacy capability may be so cost prohibitive that it crowds out the possibility of other investments that are, in combination, more valuable. Careful investment scoping includes setting criteria for when divestment of existing systems may be in the nation's best long-term interest. This is addressed for fleet replacement in the final report from SAS-099 [13].

The frame does not include everything to be addressed before the decision process begins, but only defining what must be accomplished by the decision, some of which will emerge during the decision. How the decision is reached bears directly on achieving organizational commitment to a portfolio, which is the subject of Section 5.6.

### 5.1.3 Pitfalls Avoided with an Appropriate Prioritization Frame

Attempting to improve a portfolio of investments without clearly stating its context, boundaries, constraints, and intent leaves an unmapped minefield of conflicting assumptions, expectations and cross-purposes waiting to frustrate decision-maker and stakeholder communications. Cultural blind-spots can lead to missed investment options and opportunities for efficiencies that could allow additional investments. Alternatives may be embraced that overlook resource and other limitations, reducing the likelihood of success. The risk is that the portfolio decision may be misaligned with the nation's most vital interests and fail to address significant defence-relevant problems. A clear portfolio frame can avoid these risks, providing better communication, and improved understanding and expectations of results. A well-articulated frame sets forth a higher context that helps lift stakeholder perspectives above more routinely parochial thought patterns. The necessity of revisiting the frame as new information and analysis brings new decision insights will, itself, bring a better grasp of the relevant domestic and international context, driving the decision team to further examine previously unquestioned assumptions until national requirements for defence investment are properly understood and properly structured for success. It also facilitates communication and justification of the decision elements to auditors, central agencies, and the government of the day, fostering trust that Defence is serving the interests of the nation above their own.

### 5.1.4 Topics Relevant to Decision Frame Quality

Nations can develop a better sense of how well their portfolio prioritization decision is framed by considering and discussing, at the discretion of the DM, the following questions:

- What does the portfolio decision need to accomplish?
- What will the revised investment portfolio need to accomplish?
- Is it clear what has already been decided and what will be decided later?
- Does the frame take full account of the impact of defence capital asset management on the national strategy and its assigned defence tasks?

- What issues outside the frame are most closely related to those the decision must manage?
- What issues are most likely to affect decision requirements?
- What competitor moves are most likely to change the decision or resource boundaries?
- What technological developments are most likely to change the prioritization or resource boundaries?
- What political developments are most likely to change the prioritization or resource boundaries?
- Are any change initiatives or classes of investment options excluded from the scope but able to enhance capability and/or offset the need for more costly capital investments?
- Are the defined prioritization objectives truly fundamental, or simply means to even higher decision-attainable ends? Can the prioritization achieve objectives that are more strategic than have been stated?
- Are all the prioritization objectives achievable through this decision or are they too broad for the prioritization to attain? If so, what are the true limits of what the prioritization can achieve?
- How much has the decision frame evolved since the start of the decision process?
- If one of the decisions already taken as given was not already settled, how would that change the decision frame?

### 5.1.5 Rating the Quality of the Portfolio Decision Frame

The following offers an illustration of the use of anchors as an aid to defining the frame quality dimension to assist the DM in setting a frame quality standard (100%) and evaluating the degree of attainment:

- **0% BAD – "Frame Blindness" or "Plunging in":** portfolio decision scope or assumptions are not stated; decision maker(s) not identified; and no identification of investment intent.
- **50% BETTER – "Incomplete or immature frame":** decision maker(s) are identified; issues raised but objectives remain incomplete / unstructured; the possible range of alternatives is not discussed; little reference is made to what the portfolio decision will and will not include.
- **100% BEST – "Conscious, shared perspective":** Clear statement of the portfolio prioritization purpose and scope; identification of decision maker(s) and constraints; construction of a common perspective; and consensus/agreement on the decision frame.

## 5.2 CREATIVE AND FEASIBLE ALTERNATIVE PORTFOLIOS

The concept of a portfolio can be described as "a collection of policies, projects, programs, activities [and/or] assets that may be selected for implementation and which have in common: decision makers, resource base and purpose" [14]. By their nature, portfolios aggregate and simultaneously plan individual funding decisions on all in-scope investment options. At its simplest, a set of $n$ Yes/no funding decisions are aggregated to become $2^n$ possible funded investment combinations, even more if the investment inventory includes multiple or scalable options for a given project or program. Prioritization assigns investments to one of at least two sets, including those to be funded for delivery (sometimes called prioritized investments) and those not to be funded.[13] We refer to investment options because they may or may not be included in the set of funded investments. Different prioritizations or portfolios are called "alternatives" because the DIP decision will determine a single portfolio of investment options.

[13] Beyond funded and unfunded investments, additional sets might be defined, such as those provisionally approved, first up for cancellation if total investment costs rise excessively or budgets must be reduced, and others first in line for funding should new resources become available.

The portfolio concept recognizes that funding available for any investment depends upon what else is also funded. Therefore, alternative prioritizations are synonymous with alternative investment portfolios. We use the term "Planned Investment Portfolio" or PIP because spending on some investments selected for funding may not begin until some future date.

Each portfolio alternative considered is a possible allocation of available investment funding toward the achievement of the objectives defined in the frame. The set of all alternative portfolios considered constitute the menu from which a planned investment portfolio is selected. While the number of possible portfolio alternatives may be too great to explore fully, too small a number of portfolio alternatives under consideration can signal efforts to limit deliberations or engineer a particular decision for reasons other than those in the frame. Whatever the source, when the number of portfolios considered is too small, this risks accepting a lower level of overall effectiveness or a higher level of risk than could otherwise be achieved with a given budget (or alternatively, to require a larger budget than necessary for a given overall level of effectiveness).

It may be possible to pursue an iterative process/approach to narrow the field of potential alternative portfolios. This begins with consideration of a broad range of distinct options that have a key focus area for initial consideration. Then the strengths in one Domain/Area and weaknesses in another area for different budget and threat scenarios can be explored. Presenting a well-designed set of alternative portfolios can help to elicit DM benefit and risk preferences in different areas of the portfolio. Upon presenting these alternatives additional guidance and direction may be provided that help narrow the menu.

### 5.2.1 The Investment Option Space

Before strong portfolio alternatives can be developed, an inventory of in-scope investment options should be prepared from which alternative portfolios can be assembled. Collating and reviewing investment options can be greatly facilitated using existing authoritative databases. In the absence of up-to-date databases, a detailed review of investment options becomes necessary. If the timeframe spanned by the PIP is long, it may need to include intentions to invest that are not yet embodied in a project. There may be a risk some investments are missed or perhaps held back tactically. Investments that are classified introduce further collation complexity [2]. What is most important is that the options are as complete as possible, with sufficient detail to define the benefits and with commensurate detailed costing to hold the project management to account for delivery within the timeframe and resources provided (if funded).

### 5.2.2 Investment Categories

A useful strategy for managing portfolio complexity, especially with large portfolios, is to develop a set of collectively exhaustive and mutually exclusive investment categories [15]. Ideally, each investment option is assigned to one category, and to avoid double counting, only one category. Investment categories are known as "programs" for example in the Planning, Programming and Budgeting System used to build defence budgets in the U.S. and other countries. Such categories can enable the prioritization process to be decomposed into smaller, more manageable parts by defining groups of similar and hence more easily compared investment options that contribute to the same category of investment benefit. This sets up simpler prioritization sub-tasks that specialist communities may be able to support more directly. In this way, the portfolio is conceived as the union of category-based sub-portfolio alternatives, and each sub-portfolio alternative consists of a prioritized sub-set of similar investment options. Carefully selected categories bring definition to subsequent analysis efforts according to the types of insight desired to inform the selection. An application of this strategy is illustrated in Phillips [16]. (See also Montibeller et al. [17] for further guidance.)

A frame that includes a set of portfolio fundamental objectives hierarchically decomposed into measurable sub-objectives may provide a strong basis for investment categories defined around disjoint objectives or

sub-objectives at appropriate levels for investment option aggregation. Investments can be assigned to these categories according to the objectives or sub-objectives that they most directly advance. The number of investment options in each category can be controlled (within the limits of the objective hierarchy's topology) by aggregating or disaggregating category-defining sub-objectives served at higher or lower levels in the hierarchy.

Figure 5-2 illustrates categories as vertical arrangements, each labelled as "Area A, B, C, etc." Each level within a category represents an expert judgement of how best to expend that level of resources dedicated to that category, consisting of investments in that category. The current portfolio shows the levels of investment in each category in blue, while an alternative allocation labelled investment "Scenario 1" indicates a different balance between the categories and a different allocation of resources between them.

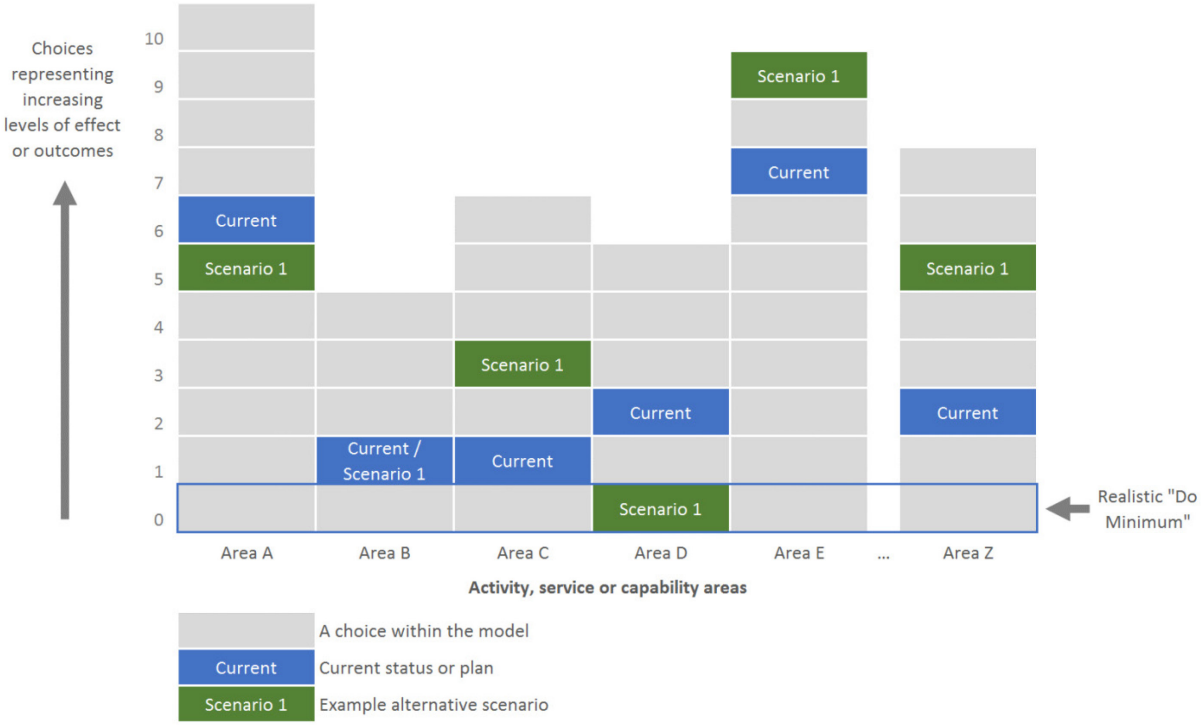


**Figure 5-2: Use of Investment Categories and Sequenced Sub-Portfolios (Source: Ref. [5], p. 6).**

Program structures in ND (e.g., major force programs, sub-programs, and program elements) offer one approach to investment categories. Sub-program categories within each program can play a useful role in prioritizing investments. Capability-based categories can also generate valuable insights into the defence-relevant outcomes of alternative portfolios, and also for budgeting purposes so long as they are mutually exclusive and collectively exhaustive.

For capital investments supporting training or more institutional programs, a comprehensive structure of mutually exclusive defence programs makes possible a mapping from deliverables to specific programs they will support. This can help set up value-indicating comparisons between expected program performance with and without investment delivery, and eventual confirmation of benefits realization.

Investment categories based on a ND organizational chart (e.g., Army, Navy, Air Force) may seem to be an obvious and natural approach but can result in duplication (or triplication) of capability and tends to reinforce the internal political dynamics that make trade-offs between investments more difficult. That said, they may be necessary if the decision frame requires a balance in funding between defence organizations.

Some investments can be difficult to categorize for a variety of reasons. They may contribute to multiple objectives or capabilities, seeming to place them in more than one category. Some may not seem to fit into any category, but this may be a signal that the set of categories is incomplete. They may need to be categorized last, based on their comparability or affinity with other investment options in each category. If some investments do not fit well into any category, the categories may need to be reviewed and augmented.

More than one category framework may be needed to support other perspectives on the portfolio, especially temporal categories, to facilitate analyses of:

- Portfolio execution burdens over time;
- Military capability realization over time with and without specific investments; and
- Aggregation of portfolio cost and affordability risk over time.

### 5.2.3 Available Benefits

The inventory of investments represents the variety of ways in which objectives could be served. Keeney [10] highlights the importance of investigating the total potential for each top-level portfolio objective to be satisfied, especially since these objectives are to serve higher level strategic defence objectives. If some objectives are only served by a few investments that promise insufficient satisfaction, perhaps new candidates need to be considered that will bolster achievement of under-served objectives.

Tate and Thompson [3], [4], note how surprisingly common it is for defence organizations to overlook or ignore worthwhile investment options, whether because of internal politics, gaps in stakeholder awareness or a lack of time to reflect. A goal of the decision process should be to encourage the emergence of valuable but previously overlooked investment opportunities. This is more likely to occur if the process involves interactions of experts with different knowledge and experience from across defence, which can serve as a natural setting for the development of innovative initiatives. Keeney's influential Value-Focused Thinking [10] recommends techniques for orchestrating and leveraging such ideation so that the investment option inventory includes a better selection of ways to fully satisfy each fundamental objective. Techniques from the NATO's Alternative Analysis Handbook [12] can be helpful in uncovering new investment options to consider in a portfolio.

### 5.2.4 High Quality Portfolios

High quality defence portfolios require strong candidate investments from which to choose. From Appendix B.6 on Decision Quality, an ideal set of alternatives to be evaluated include portfolios that are:

- Compelling, generating sufficient probability of desired outcomes to justify and stimulate thoughtful evaluation and follow-through planning;
- Cost-Effective, promising good value-for-money, or delivering as much benefit as possible for a given budget;
- Well-defined, enabling clear judgements of their actual merits;
- Feasible to implement, so that time spent evaluating them is not wasted;
- Significantly different from each other, to efficiently span the strongest portions of the frame-compliant alternative space; and
- Manageable in number, so that pair-wise comparison of portfolios is not prohibitively onerous.

#### 5.2.4.1 Good Value-for-Money

Two straightforward approaches can be used to build investment portfolios that realize as much benefit as possible, and achieve the best available outcomes from a military's limited resources:

- **Efficiency-based prioritization**, rank-orders investments according to benefit-cost ratios, and funds them from the top down until the budget is consumed.[14]
- **Portfolio optimization** uses software designed to efficiently explore alternative investment combinations to find the most valuable of the affordable investment portfolios.[15] This approach is more appropriate as investment constraints become increasingly complex, such as multiple budget periods, budgets for different resources, investment values or costs that depend upon other investments, or when value or cost information is incomplete or uncertain.

On the surface, both benefit-cost ratio ordering and optimization assume that benefits of different investments are truly interchangeable and can be aggregated into a single value dimension – that it does not matter which sub-objectives are being more or less met as long as the aggregation of value is as large as possible.[16] This may run counter to reality and the nuanced way in which a decision maker thinks about the problem of choosing defence investments. They also both assume that benefit values can be confidently modelled, and that there is no more than a modest level of uncertainty regarding what the future will require.

However, when future uncertainty makes it unclear how to model future benefit values – and which assumptions the model should incorporate – meaningful benefit-cost formulations and optimization become more difficult. Probability assignments on the relative importance of alternative future objectives become more challenging and less meaningful. If planning scenarios are being used to set the context for the value of future asset investments, unless they are each fully explored [19], [20], to define value in terms that are robust against scenario variations, they may span an insignificantly small portion of the future possibility space, making them optimal only for improbable futures.

Portfolio optimization against a rich and fully explored set of scenarios will give a better supported course of action, but a coherency analysis may still be necessary to deconflict additional requirements and constraints required for the portfolio to deliver the promised benefits. Attempting to codify these for large portfolios is a challenging task that requires careful review and oversight.

The point is that optimization and cost-benefit analysis remain valuable tools for insight generation, but they must not be used naively or slavishly. As outlined previously, recognizing dependencies within and across major capability categories creates challenges. Some of these dependencies involve the phasing of equipment solutions needed in combination to deliver their full effect. For example, a communications satellite offers value only as land, maritime and air platforms have the necessary terrestrial system connections. The optimization approach to defence investment prioritization is addressed in more detail in Section 5.5.5

The importance of recognizing future uncertainty must not be underestimated. A formulation that promises an optimum is appealing, but it is almost never the shortest path to the best decision. Investment portfolios should deliver assets that cover a broad range of possible futures. Avoiding as many as possible of the worst future outcomes may be a pragmatic way to deal with intelligent adversaries who will look for ways to exploit weaknesses. In this context, a satisficing paradigm may be more appropriate – ensuring minimally

[14] When the remaining funding is too little for the next project, there may be a combination of projects that include the next project or two (and possibly not a near-last funded project) that uses more remaining funds and promises more benefit than leaving the larger remainder unspent. Limitations in the application of benefit-cost ratios to guide individual investment decisions are discussed in Chapter 4 of Melese et al. [18].

[15] Optimization may also be used to find the lowest possible budget within which a level of value can be achieved.

[16] Other forms of optimization for which this is not true are multiobjective or multiple criteria optimization, designed to optimize more than a single objective function. Examples of this are Goal programming (with a strict priority order of objectives) and Pareto optimization, which seeks multiple non-dominated solutions (Tate and Thompson, 2016, 2017) [3], [4].

adequate coverage of as many of the most important objectives as possible [21]. These approaches are discussed further below.

There are several simplistic approaches to portfolio investment prioritization that should be avoided. These include the following:

- **Maturity-based prioritization** is when projects are approved as soon as they can present complete documentation substantiating a sound plan to meet a genuine need in a timely way at an appropriate cost with managed risks. This "race for resources" takes no account of possible future needs that may become impossible to meet given the opportunity cost of short-sighted allocations.
- **Prioritization by exception** acknowledges certain investments as important enough to be pre-assigned funds that other investments cannot spend, leaving the rest of the budget to be allocated to the readiest projects. This only partially addresses opportunity costs as future needs may receive too little consideration.
- **Value-based prioritization** places investments in rank order according to the "importance" of what they promise to deliver (e.g., benefits), ignoring their costs, and funds them from the top down until the budget is consumed. This "greatest needs" approach ignores prices and how much more benefit in aggregate could be realized with cost-efficient investments.
- **Cost-based prioritization** is value-based prioritization's absurd counterpart, rank ordering investments according to their costs, and funding projects beginning at the bottom. Funding "only the cheapest" maximizes the number of investments funded but ignores how little actual benefit is provided to meet future defence needs.

The bottom line for identifying portfolios worth analysing is that benefits and costs must be considered simultaneously in investment portfolio decisions [6].[17]

#### 5.2.4.2 Well-Defined and Feasible Portfolios

Any portfolio assessment will require that portfolios be well-defined, consisting of investments with sufficient information on the benefits they promise, their costs over time, as well as delivery schedules and the risks they face. (See Section 5.4 Relevant and Reliable Portfolio Information.)

Portfolio feasibility requires that all of the resources necessary to obtain the full benefits of investments in the portfolio are available. This is more straightforward to assess once the investment budget has been finalized, but before then, it may be necessary to work with multiple budget options that span and bracket a realistic funding range identified in the frame. The degree of budget uncertainty (max/min) should inform the number of budget estimates used, but at least three estimates are recommended where there is any budget uncertainty, providing optimistic, pessimistic, and most likely estimates. The number of budget estimates in each period of the portfolio planning horizon and their levels may change as decision participants and, in turn, the government discover the sensitivity of portfolio benefits to different funding levels.

#### 5.2.4.3 Significantly Different from Each Other and Manageable in Number

The meaning of "Significantly different" portfolio alternatives will depend on the extent of portfolio revision the government and ND are willing to entertain. Any limits prescribed on how different reprioritized portfolios can be from the original portfolio will reduce the portfolio space to be explored. These limits may emerge or evolve when government stakeholders challenge a portfolio that includes or excludes sensitive investments. Sponsoring stakeholders may also raise such challenges.

[17] In Ref. [6], Davis quotes the six initial tenets of systems analysis, of which this is the second. See Section 3.4 for all of them.

Considering too few alternative portfolios can greatly reduce the likelihood of finding a strong one, because a portfolio candidate cannot be selected if it is never considered. It is helpful to sample the feasible alternative portfolio space as broadly as possible, which requires as many alternative portfolios to be included as can be managed within the time, analytical, and other resources available.

A systematic approach to maximizing initial portfolio diversity is to explore the feasibility of portfolios containing various combinations of the costliest investments, which we call portfolio anchors. If funded, these investments will push the greatest potential value from other investments out of the portfolio – which is the definition of opportunity cost and the reason why they are most likely to receive the greatest levels of subsequent government and public scrutiny.[18] A useful orientation to DMs and stakeholders is to tabulate the cost of all combinations of the costliest investments against each possible funding level. Begin with the N "most costly investments" – at least four but perhaps more. The cost-ordered inventory of investments may suggest the most appropriate cost threshold. Calculate the total cost of every combination and divide that cost by each funding level under consideration to indicate the budget fraction consumed by the portfolio anchor. An example illustrates this in Table 5-1 for five different possible funding levels. Font colours of the fraction indicate budget fraction remaining for less expensive investments.

**Table 5-1: Portfolio Anchor Affordability Against Budget Estimates (Legacy Portfolio Highlighted).**

| | New logistic support ships | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Hardened communication network | | | | | | | |
| | | | Heavy lift aircraft fleet | | | | | | |
| **Total** | | | | Ground-based air defence system | | | | | |
| **cost** | | | | | B4 | B3 | B2 | B1 | B0 |
| **(000s)** | 1,000 | 810 | 600 | 550 | 2500 | 2200 | 1940 | 1700 | 1500 |
| 2960 | X | X | X | X | 1.18 | 1.35 | 1.53 | 1.74 | 1.97 |
| 2410 | X | X | X | | 0.96 | 1.1 | 1.24 | 1.42 | 1.61 |
| 2360 | X | X | | X | 0.94 | 1.07 | 1.22 | 1.39 | 1.57 |
| 2150 | X | | X | X | 0.86 | 0.98 | 1.11 | 1.26 | 1.43 |
| 1960 | | X | X | X | 0.78 | 0.89 | 1.01 | 1.15 | 1.31 |
| 1810 | X | X | | | 0.72 | 0.82 | 0.93 | 1.06 | 1.21 |
| 1600 | X | | X | | 0.64 | 0.73 | 0.82 | 0.94 | 1.07 |
| 1550 | X | | | X | 0.62 | 0.7 | 0.8 | 0.91 | 1.03 |
| 1410 | | X | X | | 0.56 | 0.64 | 0.73 | 0.83 | 0.94 |
| 1360 | | X | | X | 0.54 | 0.62 | 0.7 | 0.8 | 0.91 |
| 1150 | | | X | X | 0.46 | 0.52 | 0.59 | 0.68 | 0.77 |
| 1000 | X | | | | 0.4 | 0.45 | 0.52 | 0.59 | 0.67 |
| **810** | | X | | | **0.32** | **0.37** | **0.42** | **0.48** | **0.54** |
| 600 | | | X | | 0.24 | 0.27 | 0.31 | 0.35 | 0.4 |
| 550 | | | | X | 0.22 | 0.25 | 0.28 | 0.32 | 0.37 |
| 0 | | | | | 0 | 0 | 0 | 0 | 0 |

This opportunity cost analysis[19] can be done before the decision process begins and will indicate to all stakeholders the relationships between funding levels, costly investments, and residual funding available for the rest of the portfolio. The analysis could be repeated for any other resource required to achieve operational capability of individual investments in the portfolio, given an estimate of the total available and the requirement per investment.

[18] As the time-management lesson popular on the internet a few years ago states, if you don't put the rocks into the jar first, the less important pebbles and sand will prevent their entry later.

[19] Opportunity cost is addressed more fully in Section 5.5.3.

#### 5.2.4.4 Compelling Portfolios

A portfolio is compelling if it has a perceptible sense of order – a thematic coherence that leads to insight into the particular outcomes it supports. This is difficult to achieve without an overarching framework to give it structure, serving as a window on an alternative portfolio's particular attributes. A straightforward approach is to use the investment categories introduced in Section 5.2.2, illustrated in Figure 5-2. Spradlin and Kutoloski [22] illustrate compelling portfolios in the case of a smaller problem.

##### *5.2.4.4.1 Category Prioritization*

Prioritization sub-tasks may be assigned to Subject Matter Expert (SME) committees with analytical support. If ND has already adopted a portfolio management paradigm, such committees may already be standing. In essence, it is the same task in miniature as the larger portfolio prioritization, made simpler by the smaller number of more similar investment options within each category. The approaches available to evaluate the larger portfolio are likewise applicable to the smaller sub-portfolio.

The committee could be directed to study the objectives relevant to the category, paying attention to recognized capability gaps, specific performance shortfalls, relevant operational scenarios, timing gaps, quantities of systems, and intended effects or benefits to be achieved. As they become familiar with investment performance expectations, developing an appreciation for their relative expected impact on operational effectiveness if funded and delivered, the committee may be in a position to develop scoring metrics. Combining these benefit measures with cost information, a fuller understanding of sub-objective satisfaction across the portfolio frame begins to emerge.

The portfolio before undergoing review may be called the status quo or "momentum" portfolio, which would result from leaving the current PIP unchanged. For each investment category, this will imply a momentum sub-portfolio. From these starting points, according to constraints on change in the frame, sub-portfolio departures can be explored representing increases or decreases in category funding.

As expert committees define logical sub-portfolios, they need to capture the logic applied in the differences between resource levels. The order of adding or removing or exchanging investments to create sub-portfolio alternatives should take into account any known system synergies, system dependencies and positive externalities[20] and, where possible, identify operational interactions between investment deliverables and legacy systems, both in joint operations and combined with allies. The construction logic becomes useful later as the implications of alternative resource distributions between categories are explored and evaluated. Expected spending and delivery timings for each category investment level will be important to help ensure investment delivery schedules are satisfactory. This can help underpin valuable decision-maker and stakeholder conversations to validate category sub-portfolios and address trade-offs between investment categories.

Exploring the implications over various time periods can help manage risk and uncertainty by ensuring proper consideration of the following factors [15]:

- **Evolving needs:** Is the government going to underwrite new investments to address the uncertainty by allocating additional funding in future reviews or must room be made from the current portfolio?
- **Performance risk:** To what extent do later investments rely on immature technology or depend on advancements in current technology? Does more than one investment rely on advances in the same technology?
- **Schedule risk**: Will delivery delays have disproportionate impact on one category of investment or create future capability shortfalls?

[20] See Section 5.4.4 for more on investment interactions.

- **Cost risk:** Does the portfolio leave room for known patterns of cost growth as system specifications become more precise, or are current estimates presumed accurate? Is there room for cost increases that tend to accompany delivery delays?

#### *5.2.4.4.2 Prioritization Between Categories*

After validating sub-portfolios for different category funding levels, adjustments, and incremental departures from the momentum funding distribution across categories can be explored toward better combined satisfaction of portfolio objectives. Recognizing funding and cost uncertainties, categories for increased or decreased funding can be translated into thematically coherent alternative portfolios for more careful analysis against planning scenarios. From these, hybrid portfolio alternatives may emerge that capture the best features of the strongest departures from the momentum portfolio.

#### *5.2.4.4.3 Optimization*

If the number of investments is sufficiently large and the constraints and/or benefit or cost interactions are sufficiently complex, manual decomposition of the portfolio into prioritization sub-tasks may not be feasible or affordable. In this case, portfolio optimization software may be needed to systematically explore portfolio alternatives. This is further described in Section 5.5.5.

### 5.2.5 Pitfalls Avoided with Creative and Feasible Alternative Portfolios

When too few portfolio alternatives are considered, or if they are engineered to favour only one option, this can signal biased decision making. It is possible for the variety of alternative portfolios to be strategically restricted by skilful operators who wish to avoid difficult conversations, or to favour specific groups, organisational factions, or lobbies. Whatever the cause, unnecessarily limiting alternative portfolios may leave better and less risky portfolios undiscovered, sacrificing the opportunity to achieve greater capability, extra savings, or both. Portfolio alternatives that are unnecessarily limited may show very little basis for improvement, draining much of the value from the work of evaluation committees. The quality of a decision can be no better than the menu of alternatives from which it was chosen.

### 5.2.6 Topics Relevant to the Quality of the Set of Alternative Portfolios

Considering and discussing the following questions can help develop a sense of the quality of the set of alternative portfolios under consideration:

- Do the alternative portfolios differ significantly from each other or are they only minor variations on a single approach?
- Has anyone outside of immediate decision makers provided alternative thematic portfolios?
- Do any of the portfolios extend beyond our comfort zone?
- Do the alternative portfolios fully explore all the best ways to satisfy the prioritization frame?
- Have we considered expertly imagined options from “outside the box”? What is the wildest feasible portfolio that has been considered?
- Is each alternative portfolio complete and feasible, considering everything required to execute it successfully if chosen?
- Are the alternative portfolios internally coherent, with a mix of investments that make sense as a set?
- Do the alternative portfolios include those favoured by each of our key stakeholders?
- Are all the alternative portfolios strong enough to justify the work needed to evaluate them?
- Do the alternatives include the “status quo” or “momentum”?

- Is the number of alternative portfolios manageable for the purposes of evaluation and comparison?
- How confident are we the best available alternative portfolio is among those being considered?

### 5.2.7 Rating the Quality of the Set of Alternative Portfolios

The following may be used to help rate the quality of the portfolio alternatives:

- **0% "Business as usual":** a few conventional variations on the original portfolio; or one realistic portfolio alternative bracketed by two under-defined others; or consideration only of the portfolios initially favoured by dominant stakeholders.
- **50% "Creative alternatives":** significantly different, spanning the prioritization space, feasibility not fully verified, no clear winner without careful evaluation.
- **100% "Better alternatives":** refined, feasible alternative portfolios spanning the option space and combining the best features of the original set, leveraging insights from analysis.

## 5.3 CLEAR PORTFOLIO VALUES AND TRADE-OFFS (PREFERENCES AND PRIORITIES)

The overall merit of any portfolio can only be seen in aggregate once its features and the future outcomes it supports are recognized and its robustness in the face of uncertainty is understood. The definition and introduction of metrics estimating future achievement of objectives can bring more clarity to both the meaning and evaluation of objectives, and to the character of alternative portfolios.

Defining metric-based value functions and developing weights reflecting value trade-offs according to Multiattribute Value Theory (MAVT)[21] [23] can help guide the development of alternative portfolios. However, such an approach requires decision-maker comfort with and confidence in the way values and preferences are being modelled. The management of conflicting objectives must reflect the way in which the decision maker perceives the problem. Initially, this is most directly and objectively served through metrics that reflect portfolio satisfaction of specific benefit objectives, with costs and budgets viewed as constraints.

As mentioned in Appendix B.6, the use of metrics that reflect satisfaction of portfolio objectives is preferred over the use of the Analytic Hierarchy Process. In portfolio problems, AHP takes no account of project interactions or of budget consumption and, except where there are very few candidate investments, AHP requires an impractical number of pair-wise comparisons which explode factorially with the number of investment options. That said, Vargas [24] provides an illustration of AHP applied to portfolio selection. Saaty's Analytical Network Process amends AHP to address portfolio problems, but with a much higher process burden than AHP.

### 5.3.1 Designing Portfolio Benefit Assessment

The starting points for assessing portfolio merit are the benefit objectives developed in the frame. Each portfolio can be tested against each objective to assess its performance.

Where objectives are measurable, metrics can be used to assign scores that reflect a portfolio's promise to satisfy those objectives. Metrics help make each assessment criterion explicit, ensuring all stakeholders understand the meaning of the objective in the same way, and can generate more insights into the expected outcomes implied by each portfolio. Well-defined metrics can be populated by analysis staff if sufficient information or data is available. Identifying agreed-upon metrics for each sub-objective takes time and analyst involvement but can pay dividends in shared understanding and consensus building. Transparency and

[21] Multiattribute Value Theory embodies the principles of rational preference in the absence of uncertainty.

openness about documented sources of metrics and assessments applying those metrics offers an opportunity to contest assumptions that lead to those assessments, which is key to maintaining trust with stakeholders.

Many investment deliverables will be capital asset enablers of military capability and others will support the more institutional functions by which capable and ready forces are produced. As noted above, capability partitions and program performance management frameworks can provide useful structures to support the evaluation of current and future states of ND facing foreseeable challenges supported by legacy systems and investment portfolio outcomes. Clear capability and program performance metrics can support systematic scoring of portfolio benefits and reveal corresponding strengths and weaknesses of portfolio outcomes over time in the face of opportunities and threats. These frameworks are most useful when defined at the ND level, although they can also be of use in lower level organizations such as individual services proposing investments to be included in the ND portfolio.

The use of scenarios to explore foreseeable operating contexts and environments can also support the evaluation and measurement of portfolio benefits, provided:

1) The scenarios adequately reflect the range of future uncertainty the nation faces; and
2) That they are sufficiently complete and clear to suggest meaningful operational outcomes expected from a given investment portfolio.

The use of scenario's and wargaming for portfolio metric assessments must also consider the potential for biases based on knowledge of past performance (and training), and participants' potential knowledge of processes to favour particular solutions. Such use of future scenarios should take realistic account of production schedules and investment delivery, which will determine capabilities available to address time-bound scenarios. However, an over-reliance on scenarios risks overstating the level of certainty in predicting the outcomes of future events, or bias toward a particular version of the future.

It is important to understand the inputs to the value/benefit model. It will only reflect the perspectives that have informed the model. If the political perspective is not represented in value modelling, then investment options with significant political value should not be expected to fare well in a value model calibrated on principally military considerations. This highlights both the importance of the external frame to help achieve a full identification of investment objectives, and indicate which investments are subject to the prioritization process, and which are not, because their status is not in question.

It is also worth noting that some investment criteria may be intangible, or more qualitative than quantitative, which can make metric-based measurement difficult. This does not negate the importance of such criteria, and they should be incorporated as needed, possibly with scores assigned through subject matter experts, or by senior decision makers. Objectivity becomes especially important in such a case. Incentives of those involved should be considered and attention paid to reduce the risk of biases and ensure objectivity. The extent to which multiple subject matter experts disagree in their ratings can help assess the quality of information generated for use in the analysis.

### 5.3.2 Understanding Portfolio Merit

Ideally, the merit of each portfolio would be reflected in quantitative metric scores indicating their expected achievement of the benefit objectives. The significance of the scores that a metric generates can depend on their place between maximum and minimum values in the acceptable range and on their place within the distribution of actual scores achieved across relevant portfolio alternatives.

The overall merit of a portfolio tends to be better understood by stakeholders as they increase their familiarity with how much and when each metric matters, the nature of the outcomes those metrics suggest

in different scenarios, and the sensitivity of score ranges generated by value functions.[22] The evaluation of outcomes against benefit objectives may also require an analysis that combines two or more metrics in ways that reflect military capability requirements.[23] This can set up discussions of value functions and how strongly or weakly individual metrics contribute to overall portfolio merit, drawing out which metrics show greater or lesser variation. One goal of this exercise would be to help develop agreement concerning the dimensions along which portfolio merit varies most strongly. Another concern is to ensure there is sufficient governance and oversight of the analysis process to define boundaries and assumptions to avoid the possibility that other studies of the same problem produce conflicting conclusions [25].

Some future ND outcomes will be more consequential and desirable than others, and what constitutes a satisfactory outcome will depend on the objective, and where an outcome sits in the range of outcomes available for that objective. The best portfolio may be one that achieves the desired balance (trade-offs) between the combined outcomes it promises to produce. Explicit trade-offs between different types of investments and desired outcomes can be supported by benefit information and should enter into judgements of overall portfolio merit. However, rather than trade-offs, decision makers are often initially more interested in specific outcome ranges [6]. They will initially have perhaps intuitive thresholds for what is "good enough" ("satisficing") for each objective and will prefer to trade away apparently surplus performance in one objective against other objectives in order to achieve minimally acceptable outcomes for other important objectives deemed most critical. After satisficing, there may be greater interest in formally defined trade-offs and optimization-based improvements. However, explicit trade-offs are more likely to emerge after an analysis that provides the DM a clearer picture for the types of outcomes likely to be produced by alternative portfolios.

### 5.3.3 Portfolio Trade-Offs

Decision makers' ability and willingness to define acceptable trade-offs can emerge naturally through consensus or as their judgements evolve concerning the relative contributions of benefit metrics to overall portfolio merit. Where there is not a consensus, explicit trade-offs can be developed separately by decision makers and stakeholders, reflecting their distinct perspectives. Several techniques exist when quantification is possible to help guide these trade-offs.[24]

Trade-offs and value prioritization is only meaningful when made in terms of specific metric quantities. For example, stating "lives matter more than money" does not reveal what cost may be justified to save one life. This is why prioritization of objectives is not meaningful without referring to scales of satisfaction for each. Finally, note that resource requirements enter trade-offs only indirectly. Their impact is felt only in aggregate against resource availability, ultimately limiting the extent to which desired outcomes can be achieved in a given portfolio.[25]

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[22] See Section B.6.3.3 for more on value functions.

[23] Davis [6] illustrates this with the example of interdicting an invading army with air forces, which requires all four of: deployed aircraft and logistics; strong command and control with intelligence, surveillance, and reconnaissance; suppressed or evaded enemy air defences and attack and destruction of manoeuvre forces. Success in air force interdiction measured on the interval between 0 and 1, inclusive, ([0,1]) will be more nearly the product than any weighted sum of metrics reflecting success with each of these component tasks on the same interval.

[24] For example, the development of value functions that map metric scores (possibly in combination) to values (relative benefit levels) in the interval [0,1] reflecting the amount of satisfaction expected toward a given objective by a portfolio, and the relative degree of preference for increments of improvement in (possibly combined) outcome metrics. Then, questions can be posed regarding choices between levels of more preferred outcomes and (full swing) variations in less preferred outcomes to which a decision maker or stakeholder is indifferent [23] A similar approach is the Balance Beam method [26]. Parnell's Swing Weight Matrix method can also help identify trade-offs when analyst access to decision makers is more limited [27].

[25] See Section 5.5.5 on effective optimization. Keeney [28] offers specific guidance on value trade-offs.

### 5.3.4 Pitfalls Avoided with Clear Values and Trade-Offs

In the absence of attempts to develop metrics that reflect the merits of alternative portfolio choices, whether quantitative/objective or qualitative/subjective, the real meaning of objectives is left vague and likely to be misunderstood. Topics important to minority stakeholders may be left unaddressed, leading to contentious decisions. Without clear discussion of trade-offs among conflicting objectives, the opportunity to develop shared insight is lost, and with it the opportunity to manage the complexity of portfolio evaluation. The absence of clear values and trade-offs can leave DMs with less meaningful or more arbitrary ways to understand and compare alternatives. Clear trade-offs between more and less certain benefits can prevent inferior outcomes, say from decisions that assume too much risk, or do not pay enough attention to force protection. Careful analysis made possible by clear values and trade-offs make the decision process less dependent on stakeholder personalities, complex social dynamics, and special interests.

### 5.3.5 Topics Relevant to the Quality of Values and Trade-Offs

Answering the following questions can help develop a sense of the quality of portfolio benefit trade-offs:

- Do the metrics span all the dimensions of portfolio merit that matter?
- Do portfolio objectives reflect input from all those who will be directly affected by the decision?
- Do portfolio objectives reflect input from those who must implement the decision?
- Is it clear how alternative portfolios are to be evaluated against objectives?
- Who is overseeing the assumptions in any analysis and the use of scenarios and wargaming?
- Have clear trade-offs to which the decision maker is indifferent been identified between various types of benefits or achievement of outcomes?
- Have the implications of risk on the overall merit of alternative portfolios been articulated?
- Has the impact of the timing of the results of the mix of investments, including any delays, on the overall merit of alternative portfolios been articulated?

### 5.3.6 Rating the Quality of Portfolio Values and Trade-Offs

The following can be used to help rate the quality of portfolio values and trade-offs:

- **0% – "It's not clear what we want":** preferences not explicit; stakeholders not identified; "intangibles" ignored
- **50% – "Clear value measures":** stakeholders and criteria identified; fundamental objective values distinguished; trade-offs need work
- **100% – "Clear trade-offs":** explicit statement of desired results in terms of decision criteria that address fundamental objectives; explicit trade-offs made between competing criteria/objectives; non-value added objectives identified; double counting avoided

## 5.4 RELEVANT AND RELIABLE PORTFOLIO INFORMATION

Strong decisions require reliable information that addresses the questions that matter in an unbiased way. When information quality is known, including the source of data and its suitability for portfolio decision purposes, the risks of over- and under-reliance can be managed, making appropriately nuanced judgements possible. Knowing the quality of the available data is important to discovering what data improvements might be

required and the feasibility of doing so. Knowing the quality of available information helps identify the most serious sources of uncertainty in the analysis, which is critical in managing portfolio risk. Where information is lacking to develop quantitative measures, subject matter experts or decision makers might be able to provide informed judgements.

### 5.4.1 Future Defence Challenges and Deep Uncertainty

The most uncertain information bearing on DIP decisions concerns future challenges to national defence and their investment implications. As already noted, scenarios are a powerful tool for segmenting the future into plausible representative outcomes based on specific assumptions – with corresponding risks. Fully defined scenarios present easier situations for defence staffs to evaluate and are particularly useful to help identify dependencies and broader interoperability issues. However, they also often conceal a number of implicit and sometimes arbitrary assumptions and may span too little of the future possibility space to warrant much reliance as a mitigation of uncertainty.

A balanced scenario approach defines the most strategically relevant scenarios as minimally as necessary to anchor their places as future possibilities, and then defines the most consequential dimensions of scenario variation to be investigated with exploratory modelling. The robustness of investment decisions is reflected in the proportion of combined scenario variations for which future forces successfully meet scenario challenges. The development of scenarios from combinations of defining assumptions constitutes a move toward the more elaborate but also more powerful "Robust Decision Making" approach summarized in Appendix B.9 on Decision Making under Deep Uncertainty.

### 5.4.2 Resource and Investment Information

Data collection can begin by recognizing the resource assumptions specified in the prioritization frame, including funding and any other resources required to bring prioritized investments through to the realization of benefits. These should include any capacity limits on those resources, or on project management requirements (including specialized management skills, technical expertise, etc.), and limitations that might arise from the government investment approval processes itself.

Useful information for each project in the investment inventory includes:

- The project name and unique identifier;
- The associated personnel (senior sponsor, project manager);
- Its key deliverables;
- The part of the portfolio it would be in if prioritized (category or segment);
- The project's purpose (project goals, requirements, or desired outcomes; the portfolio objectives it supports and how);
- Its costs (capital and operating cost profiles, including reliance on other limited resources or skills for delivery and operation);
- Its delivery schedule (achieved and planned milestones including approval stages, particularly whether it had been approved before this decision); and
- Its risk profile (risk level and most significant execution risks).

### 5.4.3 Information Uncertainty

Richard Danzig [29] offers ten propositions about prediction and national security, noting the common human propensity to make predictions as a basis for planning, a practice deeply embedded in the

US DoD and other defence establishments, and that broad failure is assured in both Defence and life. Leftwich et al. [30] go as far as asserting "Uncertainties about the future threat environment, rate of technological advancement, and budgeting cannot be characterized with probabilities." The default practice of predicting investment information in a portfolio with point estimates implicitly denies any uncertainty, a concealment that tends to mislead decision participants, and which can undermine implementation of portfolio decisions. Overlooked limitations in information quality can have serious adverse consequences on portfolio decisions.[26] These can arise from the variety of biases to which human judgements are prone[27], and are concealed when the origins of data are not properly documented.

The explicit use of ranges of data (e.g., confidence intervals) can open up important conversations about what is not known and, more importantly, insight into what could lead to higher or lower values. Characterizing information with significant[28] uncertainty using a most probable value, and upper (95%) and lower (5%) thresholds, can bring clarity to how confident decision makers can be in the information, and also inform subsequent sensitivity analyses. Setting valid upper and lower bounds is not easy (For example, see Chapter 12 of McNamee and Celona [31] for guidance on probability distribution encoding).

It is also important to ensure that bias is not introduced in the scoring and evaluation of alternatives against objectives. If analysis is provided by organizations with specific interests in particular decision outcomes, then neutral oversight will be necessary to ensure proper "Terms or Reference" (scope and assumptions) are used in evaluations.

When the uncertainty of information unacceptably impedes portfolio analysis, it may be possible to improve on information quality through further investigations. The costs of collecting more and better data can be weighed against the impact that improved data quality is expected to have on the quality of portfolio analysis, revealing the marginal value of information improvement.

In his "Ten Practical Principles for Policy and Program Analysis"[29], Alain Enthoven, a pioneer of systems analysis at the RAND Corp. and senior analyst and executive in the US Office of the Secretary of Defence, laments that analysis training tends to assume the availability of correct information when misinformation abounds [32].[30] According to Enthoven's 5th principle "it is better to be roughly right than exactly wrong," by offering the following eight pieces of advice to mitigate the main information risks:

a) Finding the right questions and being willing to pursue them is 90% of the battle. If you can't think of good questions, ask around; perhaps others can.

b) You can't check everything – you have to believe some things – so focus on essentials. Test the sensitivity of outcomes to variations in the input data and concentrate on getting the most influential information right.

c) Good data always emerges to answer certain questions under certain assumptions. What were those questions and assumptions? How well do they match the assumptions of your analysis?

d) Where possible, develop independent sources of information and try to test your information against the implications of those other sources.

[26] For example, this can generate arbitrarily bad results when culling dominated portfolios from the set of alternatives and when ordering portfolios by value-efficiency.

[27] Appendix B.4 tabulates some of the most common individual biases and describes some common group bias dynamics.

[28] The threshold of significance depends not only on its uncertainty but also on its analysis impact.

[29] As the principles of Systems Analysis became more widely known in the US Government, its name migrated toward the now-common Policy Analysis [33]. The name of this article shows that the terminology evolution already underway in 1975.

[30] Apparently, it was as true in 1975 as it is today.

e) Look for contradictions. Do simple analyses of the different parts of the data set to see whether they fit. Such checks have been key to uncovering recent fraud scandals.

f) Randomly spot-check certain data items back to their original sources. Confirm how the measurements were made and processed to produce your data.

g) Consider the incentives facing those providing information and their biases. Are they under pressure to report progress or improvements over the reporting period? What procedures produced the information? Were there independent checks?

h) Consider information sources outside your organization. Go beyond internal consistency checks and consult other sources that ought to corroborate true information internally sourced.

### 5.4.4 Investment Interactions

The benefit contributions of individual defence investments in a portfolio are most often realized through and dependent upon interactions with other fielded systems. Satisfaction of portfolio objectives should be informed by such interactions between investment deliverables and other systems with which they will operate. Systems that enhance the effectiveness of other systems add more value than what they are generally able to do otherwise, or they may provide capabilities already partly provided by other systems, reducing the overall net benefit of their acquisition to less than the sum of the overlapping benefits.[31] Some investments are essentially dependent on other specific enabling legacy assets or investment deliverables (complements) and cannot deliver full value without them. Moreover, these enabling investments may exist only for the sake of the enabled investment. Other investments may be alternative ways of satisfying the same requirement (substitutes), in which case it does not make sense to fund more than one, unless redundancy is needed to mitigate investment execution risk mitigation value can be attributed to redundancy. The extent to which portfolio metrics integrate investment value interactions will depend upon the time and analysis resources available to support the portfolio decision.

Resource-based interactions can also influence investment affordability or feasibility. These may include investments competing for limited resources (such as expert design personnel, testing facilities, seasonal capacities, and personnel pools). This can have an impact on the timing of benefit realization of funded investments requiring selected resources, even when investments are properly funded.

### 5.4.5 Risk Information

There is typically a long delay between the beginning of an investment initiative and a deliverable's deployment into operations, typically longer than any one administration's turn in power in a democracy. Business cycles and other shocks outside defence as well as unexpected developments in the threat picture are likely in uncertain ways to affect defence funding available to finance acquisition programs. For example, the COVID-19 crisis has caused a deep and sudden economic contraction which affects budgets in all Alliance countries and creates funding risks for portfolio managers.

Even if funding is relatively stable, cost growth creates portfolio affordability risk that can affect acquisition programs. If there is a budget constraint, then if one program is allowed to exceed its share, some other programs will have to do with less. Acquisition programs use funding at different rates according to their life cycle phase, needing less money in the concept and even development phase, but considerably more for production and most of all for operations and maintenance. Hence, budget and affordability risks if not

[31] A related effect is where capability can be improved through non-material products such as innovations of doctrine (developing novel synergies with other capabilities) or training. The value of these non-capital investments overlaps what investment deliverables might provide and represent a partial substitutability, reducing the marginal benefit of capability investment. If the benefit of non-materiel innovation promises to significantly close a capability gap, then the marginal value of the material investment is only the improvement it makes over non-material innovation. Such innovations, where known, can release investment resources to meet other needs.

mitigated with contingent funding can lead to reducing the number of items purchased, delaying, or slowing schedules, or cancelling programs.

Investment risks can be attributed to some variation of information uncertainty. At the portfolio level, besides affordability risk, other portfolio-level objectives face risks when multiple investments rely on the same technology maturing, or on procurement through a single company (or monopoly supplier). The combined effect of multiple investment delays can undermine time-sensitive capability objectives. Evaluating all of these risks can be facilitated by identifying and assessing the largest potential risk contributors in the project inventory (by combining the negative impact and probability of materializing) and modelling their potential results. Influence diagrams developed for the largest and most important investments can help reveal key portfolio risks as can Decision Trees. Establishing well-defined multi-year periods can help to identify portfolios with more or less risk during specific time periods.

An extensive selection of risk management techniques is catalogued in Annex B of the SAS-093 "Analysis Support Guide for Risk-Based Strategic Planning" [34], previously mentioned in Section 3.3. It includes in Annex A tabulations of the relevant application of these techniques within planning processes like the one discussed in this study.

It is noteworthy that strategic level risks tend to be different from what can be generalized from an aggregation of project level risks; they cannot properly be inferred bottom-up and instead require distinct identification of strategic level objectives and other relevant factors [35]. An analysis of the risk factors confronting strategic objectives will provide an important perspective from which to view the portfolio and its interactions with strategic objectives as both a risk source and mitigation tool. To the extent there is expert agreement concerning the identification of these risks, influence diagrams can be used to articulate their expected development and decision trees constructed to support the design of risk monitoring and managing plans.

Some investments may plan to exploit still-maturing technology. Risk analysis should acknowledge this, for example, through the application of risk adjusted benefit scores. In cases where the benefit of the investment is uncertain and less able to be monitored, this may warrant a different acquisition strategy than investments that depend on more mature technologies.

Cost risks are especially pernicious in investment prioritization. Unless nations have a management culture that views defence budget allocations as firm commitments, incentivizing "design-to-budget" approaches[32], there may be a systematic bias toward underestimating actual procurement costs. This can undermine attempts to apply optimization approaches or efficiency-based ordering. Section 2.4 outlines several factors that increase the likelihood of cost risks. Historical records of project cost growth evolution as they mature through their lifecycles can furnish a valuable empirical basis for cost risk modelling.[33] If carefully applied to investment prioritization, this can reduce portfolio affordability risk. Weir [36] documents a regression analysis of project cost growth risks using project cost growth records. This type of analysis can enable meaningful portfolio affordability risk assessments.

### 5.4.6 Pitfalls Avoided with Relevant and Reliable Portfolio Information

Exploring and characterizing the accuracy and assumptions behind point estimates reveals the kinds of insights necessary for nuanced judgments. Otherwise, future surprises can undermine the validity of strategic decision logic in avoidable and expensive ways – financially, politically, and militarily. Exploring the provenance of vital information exposes and mitigates mis- and dis-information risks. Without explicit

[32] Finland is an example of this.

[33] There can be organizational resistance to collecting such data, especially under an "information management" paradigm ready to dispose of information with no further apparent "business use". An executive champion may be needed to shift policies on retention of project evolution records.

attention to identify and remove information biases, broad stakeholder confidence can remain elusive. Consistent scrutiny of portfolio decision information helps maintain stakeholder trust in executive leadership and safeguard against moral hazards at the executive level.

### 5.4.7 Topics Relevant to the Quality of Portfolio Information

Considering and discussing the following questions can help develop an appreciation for the quality of information supporting the decision process:

- Have intermediate factors and outcomes been identified that bear on what we want? Have ranges of possible states of nature with probabilities been defined?
- Have relationships been identified between decision alternatives, intermediate factors, and value outcomes?
- Do we know which information will explain the greatest part of our outcome uncertainty?
- Have we explored the most cost-effective ways to reduce that uncertainty?
- Have data items been specified as point estimates or as possible ranges anchored to probabilities?
- If investment costs or portfolio budgets changed, how would that impact the prioritization?
- How have cost estimates been developed?
- Have cost dependencies between components within each decision alternative been identified and characterized?
- Have risks been identified? Is it known which risks are linked and which ones are independent?
- Is the structure of the final decision clear, including the sequence in which decision components should be selected?
- Who provided information on the key uncertainties? How expert are they on the topics on which they provided judgments? Are they trustworthy and reliable?
- Have expert judgments been elicited with procedures that minimize bias?
- Do expert sources agree? If so, have any points of disagreement been captured for further consideration?

### 5.4.8 Rating the Quality of Portfolio Information

The following can be used as an aid to rate the quality of defence investment prioritization information.

- **0% "Blissful ignorance":** Not knowing how much is known or what is important. Ignoring uncertainty and so-called "intangibles".
- **50% "Informed about uncertainty":** Knowing information gaps ("known unknowns") and what is important; uncertainty quantified; interdependencies not explored.
- **100% "Knowledgeable and ready":** information unbiased, accurate, explicit (quantitative and qualitative), and based on appropriate facts; important knowledge gaps filled, and limits of knowledge explored; interdependencies understood and taken into account; sources and rationales for selection well documented.

## 5.5 SOUND PORTFOLIO ANALYSIS

The core aim of portfolio analysis is to understand each portfolio's potential to satisfy the requirements/objectives articulated in the frame, revealing overall benefits, costs, and risks. It should expose

the dependence of that analysis on assumptions regarding the future, so that portfolios whose merits persist in a broader variety of possible futures can be preferred over those shaped by arbitrary features of a narrow model of the future operating environment. The analysis should also reveal the sensitivity of portfolio merit evaluations to information uncertainty, as well as perturbations in metric scores, value functions and trade-offs. Robustness and sensitivity analyses can be aided significantly by the careful use of optimization software.

### 5.5.1 Initial Portfolio Analysis

The first portfolio analysis question is how well each portfolio satisfies the most pressing objectives, accompanied by corresponding degrees of uncertainty both in terms of satisfying those objectives and portfolio affordability. These may be conveyed with a stoplight colour scheme or other simple symbolic conventions.[34] As participants become familiar with portfolio attributes – the relative availability of investments that combine to satisfy objectives, and their affordability – then willingness to articulate specific trade-offs can more readily emerge, enabling judgement supporting the development of value functions which contribute to more efficient evaluation of alternative portfolios.

While portfolio dominance or Pareto efficiency are reasonable approaches to portfolio analysis, such dominance-based analysis effectively converts ratio and interval data into ordinal data, which can be subject to dramatic changes with small perturbations in the original data. Any use of dominance logic should be informed by an awareness of data uncertainty and sensitivity thresholds, so that the robustness of the dominant portfolio to data perturbations can be properly understood and adjusted if better data changes the results [6].

### 5.5.2 Partial Application of Analysis

Potentially useful orientation and training for new participants in the DIP process might include a conceptual review of relevant analysis methods. This could involve presenting the concepts on which the methods are based, key implicit assumptions, and descriptions of how the methods can be applied. Reviewing a few examples that illustrate how input data implies intermediate data and ultimate conclusions, can provide new participants with terms in which to think about the information that emerges as portfolios are discussed, analysed, contrasted, and otherwise explored to obtain the best balance of supported outcomes and hedges against uncertainty.

### 5.5.3 Opportunity Cost

Funding constraints are what force decision makers into careful consideration of the opportunity costs of investments included in a portfolio. The essential meaning of opportunity cost is the benefits forgone. Money spent acquiring one asset is no longer available for any other use. Whatever else the money might have been spent on is the opportunity cost of that expenditure. Hence, the best portfolio is the one with the lowest opportunity cost. This is equivalent to saying that all the investments in the inventory excluded from a Planned Investment Portfolio (PIP) constitute the most tolerable combination to go unrealised. The portfolio anchor analysis reviewed in Subsection 5.2.4.3 can be used to explore opportunity costs by showing the proportions of a portfolio budget consumed by various combinations of costly investments. The focus is not so much on the money they consume, but what they displaced that the money might have procured instead.

The true scale of opportunity cost only becomes clear in hindsight. If future uncertainty is much deeper than implied by narrow planning scenarios, investments included in the portfolio may turn out only to cover a fraction of actual military requirements. In this case, the opportunity costs of those decisions are high as the money might have been better spent on other more robustly valuable investments.

[34] Red-green colour-blindness, not uncommon among men, can confound the convenience of stoplight reporting. Early decision planning should poll stakeholders and arrange for other visual cues to be incorporated if necessary.

### 5.5.4 Modelling Investment Value Interactions

The use of additive value models is a useful analytical simplification that is only valid if certain restrictive conditions are met. When investment objectives have the properties of fundamental objectives, these conditions tend to be more readily met, because decision-maker preferences for fundamental objectives tend to be more decoupled from each other. These conditions include "preferential independence," in which the decision maker's indifference between amounts of two different types of value is unaffected by the presence or absence of any other types of value. Another condition is "weak-difference independence," in which the relative preference for different levels of one type of value is not affected by the presence or absence of any other type of value. If these properties hold, then use of an additive value model is justified, which provides computational advantages when exploring the portfolio alternative space with optimization software.

To quote Tate and Thompson, "… mapping combinations of [metric scores] to values in a way that is consistent and verifiable is a complex process, fraught with potential mistakes" [3]. To illustrate, three projects $\{A_1, A_2, A_3\}$ that could otherwise be individually chosen for the portfolio but have significant synergies between them (or be partial substitutes) invalidating an additive treatment of their respective contributions to portfolio objectives, could be replaced in the investment inventory with their eight possible combinations $\{B_0, B_1, \ldots, B_7\}$,, and a constraint to choose exactly one. Each combination would receive separate value assessments, and infeasible or undesirable combinations could be dropped, reducing the work needed. This would also address investment options that satisfy the same requirement (substitutes) in which only one should be chosen. Other ways to model non-additive value interactions between metrics include multiplicative value functions. (See Appendix B.6.3.)

### 5.5.5 Optimization

For decision makers comfortable with a portfolio optimization paradigm, there is a rich OR literature on the topic, to which Harrison et al. [37] provides a good introduction. Problems of data or trade-off uncertainty can be modelled using "Robust Portfolio Modelling" without project interactions [38] and with interactions [39]. The first steps into portfolio optimization often involve modelling portfolio merit (or overall benefit) as the sum of the modelled merits/benefits of each investment in the portfolio. This intuitive approach assumes that no investment's presence in the portfolio affects the desirability of another investment, and that the risk of constructing an unbalanced portfolio with more value of some time than is actually needed is low. Because of the difficulty of modelling the benefits of costly and sophisticated combat system, optimized portfolios often include only the cheapest and little or none of the costliest investments [37].[35] The most costly investments can also be politically sensitive, which raises questions about perceived value and modelled benefits, undermining acceptance of optimization results. Hence, optimization can be more useful after the investments that anchor the portfolio have been clarified and remaining choices concern investments of more modest value and cost.

Leftwich et al. [30] describe practical limitations of optimization models and supporting software for PIP problems:

> *… [W]hen problems have more than one objective, as is typical in the realm of national defense, simple optimization no longer holds, and a multiple-objective problem structure is required, implying trade-offs across objectives and therefore no single "right" answer. Decisionmakers then typically seek a solution that will do reasonably well across all objectives.*

While models of value toward different objectives and optimization software can assist in finding a mathematical solution, they are generally not capable of finding a diversity of feasible or "good" options. In larger portfolio problems there are challenges in accurately capturing assumptions around scheduling, and dependencies between existing and new investments, and in-year budgets, which are often constraints that

[35] In the apt internet meme about fitting rocks, pebbles, and sand into a jar, it fills the jar with sand.

only become apparent in the development of new portfolio investment proposals. Due to these limitations, such tools are most useful in facilitating the exploration of alternative portfolios, rather than identifying a specific detailed PIP solution.

This requires an approach that is somewhat at odds with the usual paradigm of portfolio optimization, which typically simplifies the decision problem by combining desired portfolio attributes/objectives into a single objective function, and searches for the combination of investments that maximizes that objective. This typically involves a weighted sum of value measures used to represent each objective. Several variations on this approach exist, which are surveyed by Brown, Dell, and Newman [40]. However, optimization software can also reveal satisficing strategies and help develop a variety of other useful portfolio insights. Brown and Rosenthal [41] provide distilled wisdom from their own experience supporting real-world decisions with optimization. Some of their key insights include the following:

1) Optimization software developed for decision support must be properly documented with an executive summary of the problem solved without and with optimization support, a math formulation with all variables, and a textual description linking parts of the math formulation to corresponding aspects of the problem. Have non-experts evaluate the document.
2) Compare optimization solutions to the status quo or momentum investment portfolio to reflect disruption. Explore near-optimal solutions for least disruption. The "Hamming distance" counts the number of bitwise changes in the binary number reflecting investment status and can be used to monitor this to both constrain and fully explore acceptable change options.
3) Plan to use the software to optimize any one objective, not just a combination. This supports hierarchical (lexicographical) satisficing by optimizing the first objective, and then constraining that performance while optimizing the next. Trying to do this in one step with weights spanning orders of magnitude will swamp lower objective performance in round-off errors.
4) Drop largely pedagogical classic sensitivity analysis for parametric analysis, using multiple optimisation runs to explore simultaneous perturbation. Apply modern algorithms and hardware.
5) Pay attention to the dual of the problem.[36] Until you have meaningful interpretations of variable duals, you don't understand the problem well enough to recognize a good solution.
6) Track and report bound on the quality of any solution, which are as valuable as the solution.

### 5.5.6 Robust Solutions

The investments in a PIP should take into account an uncertain future. As noted above, solutions for a scenario can be made robust by exploring the requirements implied by excursions from a core set of scenario assumptions. A PIP can be made more robust by developing portfolios optimized for plausible scenarios, including in the PIP every investment in the intersection of scenario-optimized portfolios, and then adding specific investments with the greatest scenario-specific hedging value-for-money [2], [3]. For a more elaborated treatment of robust decision making, see Lempert et al. [42], and Appendix B.9 for further examples and references.

### 5.5.7 Uncertainty Analysis

Uncertainty analysis addresses the extent to which results are affected by inputs to the analysis. This includes uncertainty related to investment information (including performance, cost, and schedule risks), future resource and funding uncertainties, and specified trade-off weights in aggregated value models. The analysis should explore the impact of information perturbations not just individually but in combination connected

[36] Every minimization problem has a corresponding maximization counterpart leading to the same solution. These two problems are said to be each other's dual. For example, maximizing portfolio benefit is the dual of minimizing opportunity cost [41].

back to the strategic objectives of the portfolio, also taking into account any interconnected uncertainties. It may be helpful to model the most significant near-term risks using a decision tree, or through network analysis, by analysing outcomes, eliciting probabilities for representative discrete cases in different scenarios.

### 5.5.8 Pitfalls Avoided with Sound Portfolio Analysis

Sound portfolio analysis and clear communication is required to maintain credibility in the process and achieve desired performance. Valuable time can be wasted analysing relatively less important items, leaving more important and relevant (but perhaps more unfamiliar) phenomena not properly studied. At worst, the decision may not be supported by a comprehensive evaluation of all alternative outcomes against the objectives. Alternatively, there may be unnecessary reliance on point estimates that conceal risk, or possibly a needlessly complex and time-consuming analysis that makes it difficult to conduct sensitivity analysis.

### 5.5.9 Topics Relevant to the Quality of Portfolio Analysis

The quality of reasoning used in the defence prioritization decision process may be clarified by discussing a few questions:

- Are the outcomes to be expected from each alternative portfolio characterized clearly in terms of the decision objectives?
- Which factors are most and least influential in determining the merit of each alternative?
- Does the logic used to develop the outcomes make sense to an objective outsider?
- Are assumptions clearly stated?
- What drives the principal differences in the merit of the different alternatives?
- Which portfolio outcomes face the greatest uncertainty? Which have the most predictable outcomes?
- Which dimensions of merit are most sensitive to earlier value trade-off judgements?
- Have new (hybrid) alternatives been explored that incorporate the best features of the strongest alternatives?

### 5.5.10 Rating the Quality of Portfolio Analysis

The quality of reasoning supporting portfolio decisions could be rated as follows:

- **0% "Instinctive"**: intuitive decision-maker evaluation; risk of self-serving or corrupt motives.
- **50% "Limited visibility":** key sources of value identified; important uncertainties identified; dependencies not accounted for; logic incomplete and/or with insufficient detail.
- **100% "Clear best choice":** reliable analysis of each portfolio; uncertainties, dependencies, and complexities accounted for; analysis is "as simple as possible and no simpler"; clear choice based on frame objectives, alternatives, information, and values that reflect fundamental objectives.

## 5.6 COMMITMENT TO A PORTFOLIO

The variety of benefits promised by a portfolio only emerge through its successful implementation, which can depend upon stakeholder confidence in the decision. This confidence can be attained when stakeholders accept why the decision was taken and essential aspects of its future implementation. The critical inputs to achieving shared portfolio commitment are appropriate involvement of stakeholders in the decision process

and the achievement of high decision quality in the first five DQ dimensions, and a clear and feasible portfolio execution plan. Achieving these requires careful planning. The scale of planning will depend upon how long the decision to be taken will govern portfolio implementation before the next such review. Hence, a four-year review will involve somewhat broader stakeholder consultation and a longer review process to identify a portfolio that is robust over a longer period, than would be involved for a semi-annual review.

### 5.6.1 Stakeholder Involvement

Nations are increasingly engaging external stakeholders in Defence decision problems as they manage potential impacts of supply chains, the climate, corruption, and national economies. Areas such as foreign affairs, homeland security, police and state services, finance and treasury may all have important interactions with defence roles and processes. Incorporating their perspectives into the decision process can mitigate risks in "whole-of-government" assessments and pay dividends when presenting the decision for higher approval.

Identifying relevant stakeholders to participate in ND investment prioritisation is crucial for gaining a level of awareness and endorsement (buy-in) of ND investment priorities, including specific stakeholder categories. There are those who are accountable for overseeing the governance of the process, who set the direction, manage competing interests, and break deadlocks from an enterprise perspective concerning investment resources and priorities. This group includes those charged with making and answering for decisions allocating investment funding, their superiors right up through to the national government, as well as central government agencies responsible to ensure investment decisions satisfy the requirements of their specific mandates, including other public interests to be served by departmental budgets. These interests may include management of financial risks, the national industrial base, the national economy, the government's social policies, and the government's political (re-election) risks. It may be important for these agendas to inform the content of the PIP early in the process, whether by direct participation in the decision, by consultation, or through direct or indirect input into the external decision frame.

A significant source of difficulty in DIP can be the relative infrequency of a major portfolio review and revision. For many decision participants and potentially those leading the process, it is most often the first such review they have experienced. It is likely, however, that they will have experienced lower level experimentation and project analysis which can also bring with it certain biases. For example, this may include a service specific bias (Army, Navy, AF, etc.) based on their prior experience or paymasters, and/or capability or weapon system preference bias based on their prior knowledge. The principal difficulty for them will be learning how to frame a more general portfolio problem which introduces additional levels of uncertainty and interdependence across a broader problem scope, fundamentally different from their prior experience. Another challenge emerges with job rotations, where well-informed and capable decision participants are rotated into new positions and others must take their place. The rotation of individuals in key positions in the DIP process can lead to losses in "corporate memory" that must continuously be renewed. The result can lead to wasteful efforts that "reinvent the wheel," or worse, dangerous discontinuities in investment decisions that lead to risk materialization including inferior or delayed equipment, ultimately delivered to military services. Measures to regularize DIP decisions according to best national practices can mitigate these risks.

Another important group of stakeholders are those that will depend on what the portfolio delivers to do their jobs. These stakeholders are usually most directly interested in specific PIP investments and need to be consulted to provide information into the DIP process. This group reflects the values and concerns of the military services and defence organizations that will employ and train with the delivered systems and will be instrumental in informing how the systems are used, the impact of their delivery, and their relative effectiveness. These stakeholders need to have appropriate participation in decision deliberations and may be subject matter experts involved in the supporting decision analysis. They may also be important in driving out inferior decision alternatives and in gaining support of the defence organizations they represent.

The third and possibly most important group of stakeholders are those responsible for executing defence investments. Their knowledge of execution capacity, risk factors and the impact these can have on investment performance, final costs, and delivery schedules, can play a decisive role in the realistic assessment of a portfolio and its eventual attainment of objectives driving portfolio design. If their expertise is properly leveraged so that they understand the portfolio content and the priorities driving its construction, and support it, subsequent portfolio execution risks are likely to be better managed and a significantly greater proportion of prioritized investments will deliver needed benefits. Otherwise, there may be more adjustments and adaptations necessary to overcome cost and schedule obstacles to investment delivery, and less appreciation for needed post-delivery outcomes. This can also apply to those involved in central government agencies charged with managing the government's risks. Active participation by this group of stakeholders in the PIP process can increase "buy-in" and create greater understanding of, and distributed advocacy for, the intent behind DIP decisions.

The benefits of stakeholder involvement can depend heavily on the design of the decision process and the nature of their participation. A broad appreciation for the complexity of DIP, and the variety of competing interests and objectives of the various stakeholders, may reduce the impact of more parochial agendas from specialist communities and strengthen the imperative to collaborate to resolve difficult national problems. Broader involvement of stakeholders can also modulate some of the more obviously self-interested behaviours of dominant stakeholders and bring out explicit acknowledgement of some unspoken yet critical considerations. Exposing the problem to a wider community of stakeholders may also broaden appreciation for the complexities that other communities must manage, build trust between sub-cultures, and replace sub-culture caricatures with real people confronting challenging choices. Finally, broader stakeholder involvement tends to foster increased transparency and accountability.

### 5.6.2 Decision Support

A skilled and impartial facilitator, for example an expert in decision analysis, can help manage interpersonal dynamics, recognize lines of discourse that, from experience, are not productive, and steer conversation toward insights that make strong portfolios more easily recognized. The analytical support to the portfolio decision process needs to be sufficiently versatile and agile to substantially address emergent stakeholder questions during the process [43].

### 5.6.3 Decision Process

Salo and Hämäläinen [43] pose several questions bearing on the design of a decision process and the selection of its participants. For investment portfolio decisions, the answers tend to make strong demands on a carefully planned process allowing time to work through and digest the analysis used to manage portfolio complexity. Decision participants need a process enabling them to explore, articulate, and reconcile their viewpoints to obtain a shared understanding of the decision space. Broad decision involvement is costly, and the longer it goes on, the more vulnerable a hard-won consensus becomes to the risk that external circumstances pull participants away to be replaced by not as well-informed substitutes.

Some participants will drop out of the process for personal, professional, or operational reasons. Keeping careful records of deliberations is critical to orient those who must step in to replace them. The process also needs to produce intermediate products to help stakeholders prepare for when the burden of a decision phase rests on them, and to help them build and validate their understanding of both portfolio merit and execution requirements and priorities. Final products should communicate the logic underpinning the portfolio in enough detail and situated within a sufficiently compelling narrative for implementers to understand execution priorities and ensure delivery of what is most needed. It should also satisfy central agencies and provide the government good reasons why key trade-offs were recommended.

Both Decision Conferencing (DC) and the Dialogue Decision Process (DDP) have proven versatile and effective to build consensus and understanding of what constitutes a strong investment portfolio. Both are carefully structured to use the allocated time for analysis and decisions as efficiently as possible. Besides their versatility[37], their most obvious differences are whether analytical support and process oversight is conducted in-house or contracted out. The Survey of DIP practice suggests that DDP is the model closest to a number of current national DIP practices. Most ND organizations appear to have dedicated in-house analysis teams to support their DIP process.

The DDP is primarily a carefully tuned version of best practice for consultative decision making that involves interim progress reviews. That said, there is a growing literature on real-world investment prioritization realized through Decision Conferencing, which could inject fresh insight into complex decision making under uncertainty for motivated ND organizations.

Depending on existing organizational culture and practices, the adoption of new decision processes can seem disruptive and can also change the balance of power between stakeholders. Those familiar with current decision protocols will respond according to whether they believe their interests are better or worse served by the changes. Any modifications of existing decision processes may require an empowered and trusted executive champion respected by their peers and willing to expend personal capital to improve decision processes to better achieve desirable long-term outcomes.

### 5.6.4 Review of Portfolio Decision Quality

Before committing to a portfolio, it will be useful to conduct a final review of each of the dimensions of decision quality. This can start by examining previous assessments but may need updating to provide final validation and ensure high decision readiness. Any conflict regarding the quality of previous DQ dimensions needs to be resolved, as constructive resolution enhances confidence in the best remaining alternative and solidifies the commitment needed to realize desired benefits from execution.

This validation of decision quality should review the decision frame and confirm that the preferred portfolio alternative is indeed the best way to satisfy its requirements within its scope and constraints. It should also ensure any questions arising from the process have been adequately resolved. The definition of the overall portfolio problem provided by the frame sets a standard against which the selected portfolio can be compared. Closing the loop at the end of the process can confirm in participants' minds what has been accomplished and provide a final assessment before transitioning from finding the best possible investment combination to paving the way for the presentation and, once-approved, the execution of the selected portfolio.

### 5.6.5 Execution Planning

During the decision process, any disagreements need to be explored and understood to identify distinct perspectives and consider the information driving those differences. In this way, enlightened debate is leveraged to develop insights that help drive out inferior portfolio alternatives. After a decision is taken, conflicts that arise risk interfering with portfolio execution. The resolution of substantial differences is an indication of decision readiness, signalling the need to articulate a plan that delivers the most important portfolio strengths and mitigates its greatest weaknesses.

The final decision product is a plan for portfolio execution. It represents a shift from critical evaluation of alternatives to risk mitigation.

[37] Decision Conferencing works better resolving "hot" problems, with a shared sense of urgency or importance animating the process, although such urgency might come from a legacy decision process widely acknowledged to be working badly.

To ensure delivery of the most needed investment benefits, the portfolio plan should present a clear and compelling narrative that includes what will be most important to manage in the portfolio and why. This may involve recognition of certain investments first to be sacrificed should funding be reduced. A robust portfolio execution plan should address its content, and include scheduling, staffing, budgets, and other support resources necessary for successful execution. It should recognize significant risks to achieving the desired portfolio benefits and indicate priorities for their resolution. Plans to manage the most significant risks should also be clearly articulated to ensure execution is aligned with investment priorities.

### 5.6.6 Portfolio Management Support

The delivery of capabilities involves technology, industry, sustainment, and operations that are all subject to change over time. Even more subject to change are security environment threats and challenges, and perhaps less-so, national government priorities and external strategic relationships. Most subject to change are delivery schedules, costs and deliverable performance, and changes in any of these can reduce the validity and utility of long-term strategic plans. Even regular annual planning cycles with incremental investment adaptations may be inadequate to cope with developments. The more rapidly these changes occur, the more frequently periodic reviews are needed to revisit longer term consequences of defence investment decisions. This increases financial and labour requirements to continuously review and revise portfolios. The consequence of not doing this well may entail loss of trust in defence institutions, and a portfolio management system ill equipped to address key challenges. Nations need to build systems and processes not only to support multi-year PIP decisions, but to adapt and improve those processes as required, and to inform annual reviews where applicable.

Nations act and react in the security and defence domain to defend and advance their own interests and values, and the same is true of national political parties and of domestic defence organizations. Changes in any of these may test the reasoning that elevated the selection of a portfolio and undermine the robustness of DIP decisions. Ongoing attention to the continued validity of portfolio assumptions is needed, as are provisions for interim adjustments to be validated at subsequent portfolio reviews. The portfolio execution plan should anticipate this and provide what is necessary to support these interim processes and judgements until time or change warrants the conduct of another portfolio review.

As soon as a defence investment portfolio review is completed, its robustness will continue to require small changes on an annual or even shorter basis. Governments regularly revise decisions about investments as changes regularly occur impacting those investments. The DIP process needs a certain degree of agility to manage change, while generally keeping with the intent and findings of original DIP decisions.

### 5.6.7 Pitfalls Avoided with Commitment to a Portfolio

Decisions forced through with only DM commitment, and without meaningful broad consultation with stakeholders or reflection on process quality, may risk deficiencies in framing, alternatives discovery, data collection, structuring of preferences, or the logic applied to determine the best alternative. A portfolio developed without a sound process properly informed by stakeholder expertise may not generate stakeholder buy-in and could risk loss of anticipated benefits that motivated the decision due to unaddressed implementation complexity; failed execution by unmotivated, under-consulted or ignored stakeholders; or perhaps implementation of an inferior alternative because of neglected expertise. Portfolio risks identified by experts may go unmanaged and ultimately materialize and undermine the reputation of the ND organization.

### 5.6.8 Topics Relevant to the Quality of Commitment to Portfolio

Considering and discussing the following questions can help develop a collective sense of decision readiness:

- Have we achieved 100% in the quality of the Frame, Alternatives, Values and Trade-offs, Information and Portfolio analysis? If not, where do we need to focus?
- Are there differences of opinion regarding additional work needed? How shall we resolve these?
- Does the chosen portfolio best serve what the decision frame demands?
- Will all the resources this portfolio requires be allocated to its execution?
- Are the implementers clear about what is fundamental and what is of secondary importance in this decision?
- Do major risks have mitigation plans? Can they be implemented?

### 5.6.9 Rating the Commitment to a Portfolio

The readiness and commitment to the defence investment prioritization decision can be evaluated as follows:

- **0% "Unmotivated":** lack of interest of key decision makers; insurmountable organizational hurdles; insufficient support.
- **50% "Active decision board":** active participation by the right people; commitment to achieve decision quality; commitment to "do it right the first time"; buy-in not yet pervasive in the organization.
- **100% "Take action":** buy-in from implementers, decision authorities, key stakeholders, and those directly affected by the decision; sufficient resources allocated to implement and fully execute the decision.

## 5.7 CONCLUSIONS

Successful management of a nation's planned defence investment portfolio review to achieve the best possible national outcomes is well served by reflectively seeking to achieve:

- A proper decision frame that makes clear:
  - National and Alliance interests to be served and advanced;
  - What may be required from National Defence to serve those interests in the future;
  - The full DOTMLFPI asset portfolio available for that purpose; and
  - The financial and other resources the government is likely to make available for successful implementation of the portfolio.
- A manageable and diverse number of alternative portfolios to evaluate;
- Prioritized criteria desired of the revised portfolio from which merit can be assessed, or ideally, measured;
- Benefit, cost, schedule, and risk information for individual and combined portfolio investments, rated for accuracy and curated against bias and error;
- Analysis of portfolios against specific criterion thresholds and robustness against deep future uncertainty; with an awareness of opportunity costs and sensitivity to information and judgement uncertainty; and
- A process that leverages stakeholder expertise to document and prioritize the management and execution of portfolio investments.

Ongoing assessment of how well each of these is achieved can help ensure the success of the portfolio decision process, and ultimately promise better defence investment decisions and outcomes in the long term.

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# Chapter 6 – DISCUSSION, CONCLUSIONS AND FUTURE WORK

## 6.1 SUMMARY

This study offers valuable guidance to help build and refine defence capital investment portfolios that realize desired long-term national and alliance outcomes. It combines insights from the relevant literature with results of a survey of national Defence Investment Prioritization (DIP) practices and the experience and expertise of the authors. The study starts by describing the complexities of DIP decisions, briefly introduces the elements generally in place before a formal DIP decision process begins, reviews several of the most relevant academic literatures, and reports the results of a survey developed to discover current national DIP practices in the broader NATO community. Finally, the study offers recommendations to improve DIP.

The most significant DIP complexities from Chapter 1 include the deeply uncertain future needs to meet threats, technology, and operational demands, as well as uncertain future budgets and investment outcomes. Other challenges include the many conflicting objectives and stakeholder perspectives that need to be taken into account and reconciled, and important interdependencies that exist between military capabilities, greatly complicating the modelling of promised portfolio benefits.

Prior inputs to the DIP process described in Chapter 2 include the necessary culture of institutional integrity, the formulation of defence policy and strategy to defend and advance national interests, strategic capability assessment that formulates defence investment need, and the challenges of consistent investment costing.

Relevant literature streams presented in Chapter 3 highlight the interactions between time, money and information seen in financial investments; Operational Research's (OR's) algorithmic portfolio optimization approaches; extensive NATO SAS work on life-cycle costing, risk-informed defence planning and approaches to ill-structured decision problems; The U.S.'s Systems Analysis (SA) approach to problems specifically including DIP; the perspectives and techniques brought by Decision Analysis (DA) to decision problem complexities, and vigilance to counter human biases, individual and collective; the "Decision Quality" (DQ) construct of DA, encapsulating DA sensibilities in measurable, executive-level terms; and the assumption-based approach of Decision Making under Deep Uncertainty (DMDU) to managing the future's power to surprise. It concludes by highlighting DQ's harmony with SA and its generic decision management utility.

The national practice survey reported in Chapter 4 reveals patterns in how 13 participating nations select resource constrained defence investments, showing that each has a defined process for drafting and updating those decisions on a regular basis. Almost all surveyed countries solicit preferences and priorities when reviewing portfolios and most agreed they produce a hierarchical breakdown of objectives. While a majority of nations did model portfolio benefit to some extent, few indicated that they maximize benefits using optimization tools or techniques. Risks were often considered, but seldom explicitly modelled. The key observation is that almost every part of the survey showed both the diversity of allied and partner DIP decision contexts and how varied practices are, leading to recognition of the value of principles-based prioritization guidance. This study leverages the DQ framework as a possible organizing principle and guidance for nations to improve their DIP portfolio decisions.

Chapter 5 addresses necessary elements of a portfolio review to help achieve better national outcomes within the six DQ perspectives, with guidance to rate achievement of each of:

- A proper DIP frame that clarifies the decision context, intent, and decision boundaries;
- Sufficient alternative portfolios to review that are suitably diverse;
- Prioritized criteria desired in the revised portfolio, against which merit can be assessed or, ideally, measured;

- Benefit, cost, timing, and risk information of portfolio investments, rated for accuracy and curated against bias and error;
- Analysis of portfolios against specific criterion thresholds and robustness against deep future uncertainty; with an awareness of opportunity costs and sensitivity to information and judgment uncertainty; and
- A decision process that leverages stakeholder expertise and documents and prioritizes portfolio execution management to achieve high decision quality.

## 6.2 DISCUSSION

The material presented in this study touches on a variety of related topics.

### 6.2.1 Operational Research and Defence Investment Prioritization

As noted in Chapter 3, even with OR's embrace and elaboration of DA's more quantitative tools under the heading of Multicriteria Decision Analysis (MCDA), the OR literature does not appear to offer systematic treatment of decision complexities routinely faced by public sector portfolio decision makers. Instead, treatments are narrowly addressed to processes supporting the use of algorithms in specific applications and case studies in which authors describe and accommodate complexity incidentally. OR in practice is principally focused on the development of algorithms. While these algorithms render a great many real problems tractable, enabling DA practitioners to reach for them as needed, support to the broad array of public sector decision problems requires specific management of more than just computational complexities. These include decision intent, benefit evaluation, information quality, analytic and organizational complexity, and deep uncertainty, including challenges of interpreting results from any computation. If not carefully developed and explicitly validated by the decision maker, the application of OR tools to DIP problems can lead to overconfidence in the results given the many simplifying assumptions and qualitative judgments necessary to conduct the analysis.

As reported in Chapter 4, nations appear not to emphasize optimization tools or techniques; those that claim to optimize curiously report little use of the benefit modelling necessary to optimize value for money. Factors discussed earlier such as the analytic, uncertainty, information, organizational, and political challenges, etc. may have played a prominent role in national responses preferring qualitative discussions over quantitative optimization techniques that rely on benefit modelling abstractions such as MCDA. This hypothesis may merit further investigation.

### 6.2.2 Operational Research and Decision Quality

As a succinct distillation of the DA perspective, the six-dimensional Decision Quality (DQ) framework provides a valuable addition to the OR toolbox, especially in the case of strategic defence resource allocation decisions. It brings structure to every kind of decision difficulty, locating and defining the natural seams between different complexity dimensions arising in difficult practical decisions, and allows those dimensions to be clearly distinguished for deep scrutiny, evaluation, and management, all within a clear decision context. We propose DQ as a robust conceptual home accommodating conversations in which national or professional insights could be shared within the NATO SAS community regarding capital investment portfolio decisions, and perhaps other similarly complex international decision challenges beyond National Defence.

### 6.2.3 Capability Based Planning and Defence Investment Prioritization

The topic of this study arguably relates to another SAS research task group. SAS-164 "Force Development in the Twenty First Century" is undertaking to advance the state-of-the-art of Capability Based Planning

(CBP). They are continuing work that was initiated within the Joint Systems Analysis (JSA) group by the five TTCP nations[1] to advance the international evolution of CBP. Both of the JSA publications on the topic [1], [2] include flow diagrams[2] and report that CBP culminates with a process step called "Balance of Investment" that transforms inputs of Force Development Options, Resource Constraints and Defence Priorities[3] to deliver an Affordable Capability Development Plan. In the terminology of this report, they transform the elements necessary to frame and provide alternatives to a portfolio decision into a Planned Investment Portfolio (PIP). Thus, our work provides guidance on how to complete what five nations have called the final step of their variants of CBP.

Given these complementary studies, our work only lightly touches on CBP in Section 2.3 and its supporting Appendix A.3 on Strategic Defence Capability Assessment, but includes a few relevant comments offered in Chapter 5, including the footnotes. A recent review of CBP provides some evidence of its uneven success in delivering the promised Affordable Capability Development Plan [3].[4]

The work in this report began with a somewhat agnostic position. While recognizing NATO guidance regarding CBP, the study does not assume CBP is required or necessarily the best precursor for DIP decision making. Instead, the study focus is on identifying and suggesting ways to improve DIP decisions. The current work should complement SAS-164 and offer an opportunity to test some of our findings against their own expertise and experience. To the extent our study identifies the necessary attributes of sound portfolio decisions, it provides a valuable perspective on what is required of CPB to support defence investment prioritization decisions. It is hoped that the description of the types of judgements necessary in portfolio development and analysis will motivate adaptation within CBP evolutions that better prepares the cost-informed trade-offs that portfolio decisions require.

## 6.3 LIMITATIONS AND FUTURE WORK

It is hoped that the present work stimulates dialogue in the NATO SAS community, and among allies and partners, regarding DIP. In order to advance that aim, two follow-on initiatives are proposed: a Research Workshop and an Executive Booklet on defence investment prioritization.

### 6.3.1 A Research Workshop (RWS) on Defence Investment Prioritization

A research workshop that offers the wider NATO community opportunity to share information about their own national approaches to DIP would be a valuable extension of the work documented in this report. While CBP is not a new topic of conversation in NATO, specific focus on the final step of defence investment prioritization deserves additional attention. It has sometimes proven a challenge to ensure insights generated during the CBP process cross the divide between military operational sensibilities and civilian resource manager concerns that focus more on funding and other dynamics impacting DIP decisions. Several questions that emerge from our survey of the literature and of national practice may be worth international exploration in a follow-on event. Motivating questions might include:

1) How accurate is the picture of international DIP practices painted by the study's survey data and analysis? I.e., to what extent are nations using:
   a) Explicit portfolio-level objectives;
   b) Metric-based portfolio value modelling;

[1] The Technical Cooperation Program (TTCP) is a defence scientific collaboration between AUS, CAN, GBR, NZE, and USA. Its Joint Systems Analysis (JSA) branch very much mirrored the scope of work done under the SAS Panel.

[2] See Figure A.3.1 in Appendix 3 of Annex A, supplementing the content of Section 2.3, above.

[3] These correspond directly to Ways, Means and Ends, respectively, as defined previously.

[4] The preface to this report reflects a Canadian variation on that theme.

c) Ranges reflecting information uncertainty;

d) Bias-minimization in information collection;

e) Investigation of information provenance;

f) Explicit testing of portfolio robustness against uncertainty; and

g) Stakeholder expertise to mitigate risk and enhance buy-in?

2) What informs the choice of the approaches used?

3) How useful is the Decision Quality framework as an organizing principle for national DIP practices?

4) What have national experts found to be best practices from their own DIP experience?

### 6.3.2 An Executive Booklet on Defence Investment Prioritization

Portfolio decisions are made by committees of senior executives, both military and civilian. Since responsibility for the quality of decisions rests largely on their shoulders, it may be useful to produce a booklet that shares valuable advice specifically for defence executives. However, in much the way life-cycle costing has progressed through a series of SAS studies, this advice needs to be the result of building a more thorough international consensus. The current study offers a useful launching point for these discussions but is only the beginning of what we hope becomes a well-tested body of practical knowledge offered in an Executive Booklet to help guide and improve defence investment prioritization decisions.

## 6.4 REFERENCES

[1] The Technical Cooperation Program (2004). Guide to capability-based planning. Joint Systems and Analysis Group – Technical Panel 3.

[2] Taylor, B. (2013). Analysis support to strategic planning. The Technical Cooperation Program, Joint Systems and Analysis Group – Technical Panel 3, June 2013.

[3] Young, T-D. (2021). Capabilities-based 'confusion': Why capabilities-based planning systems struggle. The Korean Journal of Defense Analysis, 33(1), March, 95-118.

# Annex A – FOUNDATIONS FOR DEFENCE INVESTMENT PRIORITIZATION

While this report provides guidance on the process of prioritizing specific defence investments, several factors in play before the task begins can make it easier or more difficult and influence its eventual degree of success. These factors are introduced in Chapter 2 of the report. Annex A provides supplementary material for the interested reader.

# Appendix A.1: TRANSPARENCY

This appendix briefly discusses risks that can undermine a nation's attempts to optimize defence portfolios. Since a nation's defence portfolio decisions help shape future national and collective security, it is critical these decisions be tightly linked to security objectives. Moreover, given scarce resources it is imperative that countries achieve the greatest possible value for money. This dual goal can be achieved with the help of analytical tools and techniques discussed in this SAS-134 study. However, several risks exist in pursuit of this dual goal. Clearly understanding these risks, and various mitigation strategies, can help achieve better outcomes for NATO allies and its partners.

NATO's Building Integrity (BI) Programme[1] explicitly recognizes how risks in defence procurement can result in countries failing to achieve their security objectives, paying more for less. These risks generally involve "The misuse of public office for private gain" [1]. Familiar examples include:

- **Bribery:** Illegal payments/promises made by vendors to public (elected or appointed) officials to influence defence contracts.
- **Extortion/Graft:** Public officials demanding payments from vendors to influence defence contracts.
- **Embezzlement:** Stealing/misusing public funds/property/equipment/supplies/services.
- **Patronage:** Public officials awarding special favours (contracts; promotions; desirable assignments, etc.) in return for political support.
- **Nepotism:** Public officials awarding special favours (contracts; promotions; desirable assignments, etc.) to family and friends.
- **Careerism:** Public officials advancing their careers (pay, promotions, etc.) at the expense of the interests of the nation they are charged with serving.

Even mild forms of corruption can be a heavy burden resulting in:

- **National Security Risks**
  - *Performance Shortfalls and Schedule Delays* that impact readiness, and place military personnel at greater risk, operating with inferior equipment, services, and supplies, weakening the effectiveness of the alliance
- **Government Deficits** and **Debt**
  - *Higher Costs* for defence Equipment, Facilities, Services and Supplies that impact other defence programs, harm other non-defence programs, and that can increase *government deficits and debt*.
- **Loss of Credibility: "Hearts and Minds"**
  - *Loss of Popular Support* for the military, cuts in defence budgets undermining the credibility of the Alliance, reducing Foreign Direct Investment, slowing Economic Growth, generating Poverty and Social Instability.

To counter these risks, NATO offers:

1) A diagnostic tool to help assess risks, the "Self-Assessment Questionnaire (SAQ)" [2];
2) A practical guide to address the risks, the "Compendium of Best Practices" [2]; and
3) Various training modules to help nations implement recommendations to mitigate the risks.

[1] https://buildingintegrity.hq.nato.int/

NATO's Compendium of Best Practices [3] recommends a combination of prescriptions that involve: Building Integrity, Increasing Transparency, and Improving Accountability (See Chapter 2 in [4]). Section 7 of the SAQ [2] specifically addresses Procurement.

SAQ questions relating to "Building Integrity" include: Who is responsible for procurement in the Defence Ministry and armed forces? What are the rules for rotation of personnel in sensitive positions? What is the requirement for the declaration of assets or gifts or conflicts of interest? Is the procurement function subject to periodic or random reviews for integrity and ethics?

SAQ questions relating to "Increasing Transparency" include: What is the complete defence procurement cycle from assessment of needs to implementation of the contract? What are the procurement oversight mechanisms? What safeguards are in place to prevent requirements from being shaped such that there can only be one supplier? **What are the decision-making mechanisms?**

In the spirit of increasing transparency, a key contribution of the current study is to share decision-making mechanisms, tools, and techniques from the literature, and those used in practice, to help revise defence portfolios in ways that support the dual goal—linking portfolio decisions to security objectives and achieving value for money. This requires a clear and unbiased process that helps:

1) Detect current and future threats;
2) Develop a strategy to address those threats;
3) Identify capabilities required to realize the strategy;
4) Assess capability gaps; and
5) Identify investments that could fill those gaps.

In the spirit of "Building Integrity" individuals at each stage in the process need to be carefully screened and selected to avoid conflicts of interest and any temptation to steer investment decisions in a way that limits competition and favours specific suppliers. Independent oversight, including by Parliamentary committees, can also "Improve Accountability."

Given limited budgets, this and other SAS studies can be applied to help guide decision makers to select the best mix of defence investments to address current and future threats. (For example, See Footnote 6 on p.77 of the Compendium [3] for references to several NATO studies on Life-Cycle Costs.) However, even when defence portfolio decisions are tightly linked to national security objectives, excessive bundling, rigid technical specifications (and evaluation criteria), and surfeit security requirements can limit the number of competitors, resulting in higher costs and lower value for money. Chapter 7 on "Defence Procurement" in the Compendium of Best Practices [3] offers valuable guidance for Nations to avoid and mitigate many of the risks discussed in this appendix.

## AA1.1 References

[1] Svensson, J. (2005). Eight questions about corruption. Journal of Economic Perspectives, 19(3), 19-42.

[2] NATO (2021). Building integrity self-assessment questionnaire and peer-review process: A diagnostic tool for national defence establishments. In: Building Integrity and Reducing Corruption Risk in Defence Establishments. https://www.nato.int/cps/en/natohq/topics_118004.htm

[3] NATO (2010). Building Integrity and Reducing Corruption in Defence: Compendium of Best Practices. Geneva, CH: The Geneva Centre for the Democratic Control of Armed Forces. https://buildingintegrity.hq.nato.int/Compendium.aspx

[4] NATO (2010). A strategic approach to building integrity and reducing corruption in defence. In: Building Integrity and Reducing Corruption in Defence: Compendium of Best Practices, Geneva, CH: The Geneva Centre for the Democratic Control of Armed Forces, 13-21.

# Appendix A.2 – STRATEGY AND POLICY CONSIDERATIONS IN MILITARY INVESTMENT PORTFOLIO PRIORITIZATION

Whilst the focus of this report is on the Defence Investment Portfolio (DIP) problem, this appendix provides the policy and strategy components that frame the DIP problem. Often these subjects are treated as semi-independent activities in military planning activities. This appendix explains and challenges that thinking, arguing that in contemporary strategic planning for Defence and National Security problems a broader and more integrated strategy and investment planning cycle is not only important but a critical enabler for informing decision making.

The semi-independent separation of activities has been enabled by a period of stability since the end of the Cold War. The period that was characterized by cooperation has concluded. This has directly impacted government policies and National strategies for defence and security. Partnerships and levels of cooperation have been challenged. Rising powers have learned to shape and influence others through the application of all means of National power. This has not corresponded with a decrease in the use of hard military power, but with greater nuance and coordinated use of soft power to gain a relative advantage under the threshold of war. Change, and the pace of change influence the need for continual revision of policy and strategy. All of these factors shape and influence the DIP problem and the need for a more integrated approach.

Military investment portfolios sit within National frameworks to achieve strategic interests in conjunction with all other elements of National power. The strategic interests shape the priorities and decision making of governments. These require ongoing curation as both internal domestic political circumstances and external relationships evolve. Investment planning must translate these needs into a funded, realizable DIP that can meet planned and unexpected threats. Or as Grey described “to make systematic provision, for the possible or probable menaces to their security that include the threat or use of military force” (Ref. [1], p. 5).

A conceptual framework that was developed by Millet and Murray [2] is utilized here to provide a connecting thread between the vertical layers of analysis and planning that integrate all of the analysis that supports and informs DIP decision making. These layers include Military-Political Effectiveness, Military-Strategic Effectiveness, Operational effectiveness, and tactical effectiveness. In practice, much of the DIP problem has traditionally focused on the operational effectiveness layer as this is where large capital investments deliver benefits in the form of effects that might be, for example, in providing physical mobility, informational or combat engagement effects. With the changes in the strategic environment, the interconnection with strategic and political layers becomes much more important.

Planning during the period of stability reduced focus on strategy as technology advances shaped focus areas for DIPs. With the end of the period of stability Colin Gray provides several reminders for linking strategy and DIP, stating that “In war, adversaries can be well known, but in peace and between wars military strategies and intent are not always well known” (Ref. [2], p. 9). The impact of this is that “There can be no evasion of the inconvenient reality of the adversarial nature of every general context for strategy and its defence planning function” (Ref. [2], p. 10).

## AA2.1 Re-Emerging Challenges in Policy and Strategy that Impact the DIP Problem

The re-emergence of strategic competition has impacts on policy and strategy that has profound implications for the assessment of effectiveness at several levels and the DIP problem. Developing an understanding of an adversary’s perspective and likely reaction can aid the testing of goals and assumptions to build greater legitimacy and robustness in a strategy or strategy options that have direct flow through to the DIP.

This deliberately challenges the national strategy options by taking a view from the adversary perspective, using knowledge of their strategic culture and resources. Developing such awareness has become increasingly important to counter grey-zone and more unconventional warfare in the more interconnected world.

An exemplar of the adversarial model applied to assessments at the strategic level is that of 'strategic net assessment', utilized by the Office of Net Assessment in the United States for many years. This type of assessment is becoming more relevant again where levels of influence and deterrence are being considered across national boundaries, with new regional challenges and partnerships. The use of net assessments was once a remit of great powers, but a variant of it has recently been implemented by the United Kingdom [3]. This is evidence of concerns about dealing with complexities in a multipolar world, with increased competition, and with obvious impacts on the DIP problem.

## AA2.2 Political, Strategic, Operational and Tactical Effectiveness, and the DIP Problem

At the political level, National or Grand Strategies are periodically tested in liberal democracies through election cycles or episodic strategic updates, where declared policy is affirmed or revised. This is where interests are emphasized, and messaging to internal and external audiences is espoused. Investments in forms of National power are adjusted to fit the narrative of the day. Defence processes, whilst responsive in a tactical and operational sense, require the foundations of strategies to be reconsidered. For large bureaucracies, this is a challenge. It takes time to engage across, and reach a consensus, with stakeholders (including the government) on what has changed, and what response is necessary. The "So What" at the strategic and political level needs to flow through and be aligned with the military strategies, operational concepts, and plans which is where the interface to the DIP is critical.

Assessment of alternative strategies is becoming increasingly important and this needs to be done in a timely and considered way. This challenges organizations who have developed processes, concepts, and behaviors for the legacy problem, characterized by extended analysis periods, with long investment horizons and procurement timeframes which shaped thinking around options in the DIP at the operational and tactical levels. This re-emergent problem of strategic competition challenges the steps and assumptions made through the DIP process.

For success in strategic assessment, senior military officers in conjunction with civilian counterparts are required to test assumptions and seek to avoid their own cultural biases. Military and civilian teaming is an important attribute to maintain a clear-eyed "helicopter view" of the analysis. Transparency in collecting assumptions and documenting value judgments is crucial to build and maintain the trust of stakeholders. For adjustments from a strategic assessment to be able to flow through to the operational level and into the DIP requires organizational agility and recognition of the need for change. Change in strategy will necessarily see challenges to existing assumptions at the operational level of assessment, and organizationally. This challenges biases and long-held views and processes.

Framing an investment problem requires a nuanced understanding of the policy and strategic environment. In Gray's words "there are ways to deal with uncertainty, but there needs to be caution when claiming to be capable of modelling uncertainty". There is an appetite for governments and ministers to receive the best possible evidence from the analysis. It is common at the operational level for modelling to be conducted using quantitative methods, but the analyst should also know the limitations of the analysis and understand the approaches used.

As recognized by Williamson and Murray, the use of requisite knowledge at the strategic and political levels of assessment is important. It is problematic to use the knowledge of tactical officers to derive strategic impacts [4]. It is common practice to utilize qualitative judgments of officers in wargames to infer a level of impact, consequence, and certainty. The desire to tackle uncertainty with mathematical solutions to problems is an irresistible challenge for those wishing to apply a scientific lens. Drawing more than key insights regarding gaps or deficiencies from such wargames can be misleading and open to hidden, or not so hidden, biases.

The operational level of assessment can be characterized by approaches similar in their design to Capability-Based Planning (CBP) methods [5]. Derived from RAND work originally and applied in different

ways across the FVEY community, it fits across the strategic and operational levels of assessment. Its inputs are derived from government priorities and a strategy. The use of these approaches has aligned with the period of stability and cooperation since the end of the Cold War. As the world moves from the unipolar environment greater emphasis is required to revisit the inputs, in policy and strategy revision, into models like CBP.

The CBP model is a simple model to distil what is in practice much more complicated, but it also has limitations in its application for understanding and examining the strategic and political levels, where gamesmanship and action and reaction become more important. Whilst accepting the limitations of the model, some of which de Speigeliere [6] highlights, it contains the core needed for assessment and re-assessment and building and maintaining an evidence base. If done well, and iteratively, the CBP process builds knowledge and expertise that is still necessary for supporting the strategic and political assessments.

To support the application of the layered model outlined here a set of guiding principles has been developed. These align with the vertical layers in the conceptual framework developed by Millet and Murray [2] and are summarized in the diagram on the following page. As indicated in Figure AA2-1, connection between layers represents elements of top-down and bottom-up influences in the planning process.

## AA2.3 Outlining the Key Principles for Managing Defence Portfolios

Each of these principles is considered to some degree across the Defence planning process which frames and includes the DIP problem. Many of these are self-evident, but not always articulated in the documentation.

### AA2.3.1 Military-Political Effectiveness

**Identifying National interests.** National interests are aspects of national life important to the identity and wellbeing of the nation, including those that are vital to its survival as a nation. They are important drivers of the portfolio that are often enduring in nature. They are influenced by political factors, partnerships, and relationships.

**Identifying threats to National interests.** Threats to national interests include any factors that might prevent the defence and advancement of national interests.

**Military options for contributing to National power and interests – Hard and Soft Power.** For the Defence investment problem, we focus on the understanding of the application of military power. Whilst this is traditionally done in the sense of hard power, there are also elements of soft power and influence to consider. This would also consider the implications of coalitions and partnerships.

**Implications of Defence/Military Contributions to National Interests.** This considers how the Defence establishment contributes to other National capabilities, which could be through areas such as economic, informational, or cultural benefits.

**Resource cost for levels of National military effects.** Resourcing levels for Defence portfolios are often expressed in terms of the percentage of Gross Domestic Product (GDP). Total costs are considered including workforce and capital.

**Assessments of Option Impacts – Net Assessment.** This level of assessment is largely a qualitative assessment. It provides a diagnostic assessment of military strategy and options impacts toward the achievement of the political level objectives. In more formal processes this is a two-sided assessment of the ability to influence and understand actions and reactions.

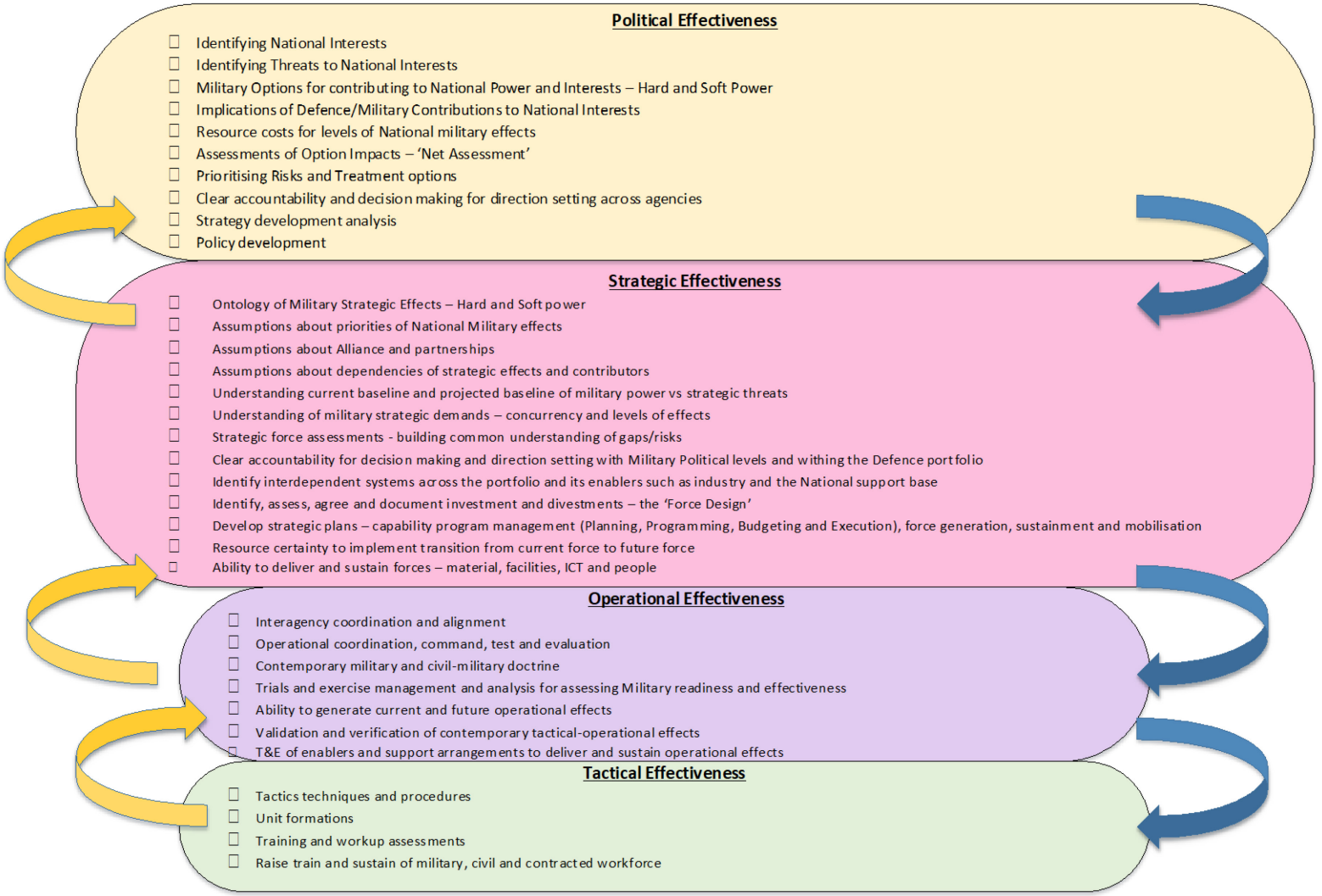


**Figure AA2-1: Guiding Principles in a Layered Model of Effectiveness.**

**Prioritizing Risks and Treatment options.** At this level, broad risks and treatment options may be specified. Particular treatment options may be discounted or preferred due to political factors.

**Clear accountability and decision making for direction setting across agencies.** Clear accountability provides endorsement and direction setting.

**Strategy development analysis.** This may assess the effectiveness and efficiency of the analysis and advice coming from the subordinate effectiveness layers.

**Policy development.** Policy development follows other analyses and is providing updates or clarification of existing policies or introducing new policies for other elements of the portfolio to follow and implement.

### AA2.3.2 Military-Strategic Effectiveness

**Ontology of Military-Strategic Effects – Hard and Soft power.** This aims to develop and maintain an exhaustive and mutually exclusive set of strategic effects that must be achieved by the enterprise. This notes that dependencies exist that are likely to prevent the design of mutual exclusivity.

**Assumptions about priorities of National Military effects.** Broad assumptions about priorities of strategic effects are important to be able to align to political objectives and to shape the direction of underlying operational effects.

**Assumptions about Alliance and partnerships.** Assumptions about alliances and partnerships help define boundaries and constraints for underlying operational level considerations.

**Assumptions about dependencies of strategic effects and contributors.** Clear articulation of dependencies between effects and contributors to these effects builds a common understanding of the inclusions and exclusions used in the framing of the military force posture – encapsulating presence, structure, and preparedness perspectives.

**Understanding current baseline and projected baseline of military power vs strategic threats.** Building a common understanding of the existing force and its projected capability excluding elements that are yet to be endorsed by the government. This includes current threat projections.

**Understanding of military-strategic demands – concurrency and levels of effects.** Defining demands and needs that include levels of threat, likely mission types, force packages and duration, and the levels of concurrent activity assumed in the strategy.

**Strategic force assessments – building a common understanding of gaps/risks.** Synthesis of assumptions, force understanding, and demands build a high-level force assessment of gaps, risks, and opportunities.

**Clear accountability for decision making and direction setting with Military-Political levels and within the Defence portfolio.** Defined accountabilities to govern processes, set priorities, develop, and present alternatives across the portfolio that minimizes biases or preferences.

**Identify interdependent systems across the portfolio and its enablers such as industry and the National support base.** Developing an understanding of higher level systems dependencies and flows of resources across the portfolio and into other supporting systems such as industry and academia.

**Identify, assess, agree, and document investment and divestments – the 'Force Design'.** Develop strategic options that can be realized within a prescribed funding envelope. This includes investments and all of the enablers.

**Develop strategic plans – capability program management (Planning, Programming, Budgeting, and Execution), force generation, sustainment, and mobilization.** Translating the force design into executable plans.

**Resource certainty to implement the transition from the current force to the future force.** Building detailed cost estimates of force design that captures all design assumptions and resource needs and gaining agreement from finance stakeholders and government.

**Ability to deliver and sustain forces – material, facilities, ICT, and people.** Engaging stakeholders to validate delivery feasibility, based on scope assumptions and undertaking a detailed analysis of supportability and sustainment.

#### AA2.3.3 Operational Effectiveness

**Interagency coordination and alignment.** Confirming operational linkages and need-lines with other agencies.

**Operational coordination, command, test, and evaluation.** Understanding current operational concepts and future options.

**Contemporary military and civil-military doctrine.** Documenting endorsed methods and lexicon.

**Trials and exercise management and analysis for assessing Military readiness and effectiveness.** Conducting operational analysis and reporting and building capability for assessment of operational effects.

**Ability to generate current and future operational effects.** Building understanding and reporting of assumptions for the generation of operational effects from force elements.

**Validation and verification of contemporary tactical-operational effects.** Developing and applying metrics for the assessment of effects in a contemporary battlespace.

**Test and Evaluation of enablers and support arrangements to deliver and sustain operational effects.** Developing methods and capability to test and assure delivery of operational effects.

#### AA2.3.4 Tactical Effectiveness

**Tactics, techniques, and procedures.** Plans to consistently achieve tactical effects.

**Unit formations.** Consistent definitions of units from systems, subsystems, and workforce.

**Training and workup assessments.** Metrics for the achievement of military tasks.

**Raise train and sustain of the military, civil, and contracted workforce.** Training, facilities, and support functions.

### AA2.4 References

[1] Gray, C.S. (2014). Strategy and defence planning: Meeting the challenge of uncertainty: Oxford University Press, p. 5.

[2] Millet, A.R., Murray, W. (1988), Military Effectiveness Volume 1: The First World War. Allen and Unwin Inc.

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# Appendix A.3 – STRATEGIC DEFENCE CAPABILITY PLANNING

The core of defence planning involves shaping a future affordable force structure to achieve the level of ambition required to meet near and longer-term security challenges. In general terms, defence planning seeks to ensure that a nation or an alliance has the necessary force structure – military personnel, equipment, facilities, and capabilities at sufficient levels of readiness - to fulfil necessary tasks arising from security and defence strategies. For that reason, defence planning can involve a complex interdisciplinary, interagency, and iterative process that comprises a large number of factors and overlapping areas, such as politics, economics, defence management, supply chains, R&D etc. Several of these factors not only apply to the defence investment prioritization problem but are also integral to long-term defence planning. Defence planning is unique in some respects in that it involves the relatively distant future which creates multiple challenges as a result of uncertainties and contingencies from a constantly changing security environment.

Defence planning can be defined as a process that aims to build military capabilities – forces and equipment, etc. – that a state or alliance deems necessary to satisfy its ambitions to confront current and future threats. It is important to differentiate between defence planning and operational planning. The latter focus is planning the use of military capabilities in the eventuality of the crisis, conflict or external operation. The aim of the former is to produce capabilities that can be used in operations.

For example, NATO's "**Critical enabling capabilities**" include:

- Joint Intelligence, Surveillance and Reconnaissance.
- Alliance Ground Surveillance.
- NATO Airborne Warning and Control System.
- Alliance Future Surveillance and Control capability.
- Ballistic missile defence.
- Air command and control.
- Federated Mission Networking.
- Cyber defence.

Capability-Based Planning (CBP) constitutes an integral part of a complex process, i.e., defence planning. This process is generally designed to investigate possible future operating environments and develop plans to shape a nation's defence organizations and military force structures to succeed in those environments. It can be assumed that a carefully designed defence planning process should ensure cohesion across various planning disciplines, so as to achieve overall force cost-effectiveness over the long term. Since the identification of capabilities needed to achieve defined objectives and the subsequent development of those capabilities is considered a key aspect of the overall defence planning process, CBP should not be seen as an isolated stand-alone process.

CBP can be considered a part of the overall defence planning process, which includes other planning domains, in particular financial planning (e.g., cost assessment), force programming, defence budgeting, and armaments acquisition programs. The main challenge for political decision makers and defence planners is to identify significant security and defence threats that could potentially hamper national or collective interests and subsequently, to evaluate alternative affordable means to be used in order to effectively eliminate or at least mitigate evolving security threats. From this perspective, the development of capability requirements through the initial planning process provides the critical information and foundation necessary for the development and implementation of medium- and long-term investment plans.

## AA3.1 Introduction to the Focal Point of Capability-Based Planning (CBP)

The current spectrum of approaches to overall defence planning and capability-based planning must confront multiple challenges including time constraints, costs that rise as requirements become better defined, the need for increasingly capable information systems, and pressure for rapid delivery of new capabilities. Capability development plans must assist and inform defence investment prioritization, so that procurement and acquisition programmes enable military forces to fulfil ambitions as outlined in defence and security policy papers. Delivery of required military capabilities to the respective forces and services is the final outcome of this process. The sequence from strategic level of ambition, through identification of capability requirements and capability assessment, followed by identification and prioritization of capability gaps, and ending with implementation of an armaments program, is the process generally applied within all NATO and partner nations. The fundamental enabler of the final step and the focus of the current work, missing from the sequence, is the identification of the affordable portfolio of investments that will close as many of the most critical capability gaps as possible.

## AA3.2 A Generic Framework of the Defence Planning Process

Whatever the approach to defence planning, a common denominator is the generic paradigm by Lykke [1] of "Means-Ways-Ends." This can be translated into a series of questions:

- What do we want to do (defence objectives)?
- What do we need in order to achieve what we want to do (capability requirements)?
- How do we satisfy identified needs (force structure and armaments programmes)?
- How much does the satisfaction of capability needs cost (resource/financial management)?

Considering the Means-Ways-Ends paradigm, capability-based planning could be seen as a framework for:

- The identification of capability requirements (ways) needed to achieve desired ends;
- Capability gap assessment, or analysis of existing capabilities against future capability requirements;
- Capability development plans, a final phase describing resource measures (means) necessary to achieve the desired capabilities.

Scenario-based planning utilizes a representative set of threat environments for the employment of forces. The environments are specified in terms of operational parameters and form the test bed for assessing capability or system requirements against formulated mission objectives (Ref. [2], p. 4). Once the capability requirements are defined, the most cost-effective and efficient physical force unit options to implement these capabilities are derived through a process of defence investment prioritization.

## AA3.3 General Approaches to Defence Planning

Different general approaches have been applied to this complex area over the years. Two approaches seem to be prevalent throughout the defence planning community: resource consciousness (a milder form of bottom-up resource-constrained planning) and scenario-based planning. Although there are many different models and approaches to defence planning, the NATO Handbook on Long Term Defence Planning [2] focuses on the following three approaches:

- **Capability-Based Planning (CBP).** A planning method described by Paul K. Davis at the RAND Corporation in 2003 just after the handbook was published [3]. Named for its focus on modular, abstracted capabilities, this approach involves a functional analysis of expected future operations. Defence capabilities are identified based on the mission(s) the forces are given. This is performed in the face of threats whose degree of definition depends upon national CBP variants, spanning

foreseeable circumstances and somewhat generic missions that together approximate the nation's level of ambition.[2] Implementation of CBP varies, with the model referred to in this appendix noting its component tasks in logical sequence.[3] The outcome of such planning is often not specific weapons systems and manning levels. Instead, this form of planning identifies the tasks to be done and generic capability levels needed to accomplish them.

- **Scenario-based planning.** This approach utilizes a representative set of hypothetical situations (threat environments) for the employment of defence forces. The situations are specified in terms of environmental and operational parameters. Defence capability requirements are determined from assessments of the ability to achieve formulated mission objectives.
- **Threat-based planning.** The threat-based approach involves identifying specific potential adversaries and evaluating their capabilities. Defence capability requirements are based on the criterion of defeating the enemy. Quantitative and qualitative solutions are explored. This was the common planning approach employed during the Cold War. It differs only from scenario-based planning in that humanitarian and other non-threat scenarios are excluded from the scenario set.

The different approaches have all been applied in recent decades, especially during the Cold War and subsequently during the Post-Cold War period. While the threat-based approach to planning in combination with scenario-based planning was typical for the Cold War period, the Post-Cold War period up to this point has mostly been characterized by a combination of capability-based and scenario-based approaches to planning due to the diffuse threats and complexity and uncertainty of the current defence environment. Today, most national defence planning processes involve some combination of these three approaches. Some may be emphasized over others depending on the defence environment facing the nation.

Nonetheless, capability-based planning has become a central theme of defence planning in the western world. Capability-based planning is related to the objective of transforming forces to deal effectively with the changes taking place in military affairs. The main reason to use capabilities (instead of dealing with force elements) is that the separation of requirements and solutions provides a mean to encourage planners to consider alternative solutions and move from service-oriented thinking to jointness.[4] Of course this was the original goal in identifying desired military "programs" (analogous to capabilities) in the Planning, Programming and Budgeting system (PPBS) also developed by RAND in the 1960s.

The NATO Defence Planning Process (NDPP) is a good example of capability-based planning applied to counter emerging security risks that jeopardize the security and stability of the Euro-Atlantic area. Most nations today have tailored their own versions of CBP to their political/military system, culture, the size of the nation, the availability of analytical support, their methodological maturity, and so on. Post-cold-war developments of the NATO, Five Eyes alliance (US, UK, Canada, Australia and New Zealand), and Norwegian approaches to CBP are described in the following publications: *Guide to Capability-Based Planning* [4] and *Analysis Support to Strategic Planning* [5], *NATO Handbook on Long Term Defence Planning* [2], and the *Norwegian Approach in Norwegian Long-Term Defence Analysis – A Scenario- and Capability-Based Approach* [6].

[2] An illustration of nation variety in CBP practice is seen in differences between the description of CBP in the NATO Handbook on long term defence planning and Davis' work on USA treatment of the same topic, available for download from RAND.

[3] The authors note that CBP does have its critics, (the present work, on just its final task, acknowledging a problem) but we contend that its principles largely align with best practices.

[4] For example, to replace old frigates with new frigates might lead to an inappropriate force structure that results in new vulnerabilities and critical capability gaps in an evolving defence environment.

## AA3.4 National Approaches to Capability Planning

Most nations have a national security and defence strategy process that establishes political objectives from which an appropriate level of ambition is agreed. Defence and military decision makers are subsequently tasked to translate this level of ambition into military operational requirements. Defence plans and prioritized procurement programs are the key tools for fulfilling operational requirements; the military capabilities developed to use what they deliver to the armed forces are the ultimate outcome.

From this point of view, national capability planning is typically placed in a wider context of security strategies and their implementation. Therefore, the aim of national capability planning is to provide a framework within which all planning activities can be harmonized to meet agreed targets in the most effective and efficient way. It should facilitate the timely identification, development, funding, and delivery of the necessary range of forces that are appropriately prepared, equipped, trained and supported to undertake the expected spectrum of operations and missions. Nevertheless, there is no universally employed method for capability planning. The diversity and fragmentation of national approaches to defence planning can be attributed to different political, economic, social, and historical experiences impacting national strategic concerns, which in turn, are entrenched in national security and defence policies. Many military planning methods have been adapted from the economic or commercial sector and subsequently tailored to reflect specific national defence landscapes. A general methodology is described in Figure AA3-1.

The steps outlined in Figure AA3-1 may have different names and might be organized differently in different nations, but they correctly identify the logical dependencies between the discrete tasks that any nation's CPB must include to inform an investment plan, whether in nations or by NATO. The first tasks are to obtain government guidance, forecast the future security environment, and establish defence priorities by developing scenarios. Scenarios are often specified in terms of environmental and operational parameters and form the test bed for assessing capability or system requirements against formulated mission objectives (Ref. [2], p. 4). The number of scenarios used, and the extent scenario parameter exploration will determine the robustness of the conclusions they can generate and the extent of their support to adjustments in the political level of ambition its armed forces must support. The political sensitivity of the scenarios and the analysis they enable necessitates transparent high-level scrutiny and endorsement of the entire process. Since the ideal level of ambition might not be affordable in practice, it may be necessary to iterate over these scenarios.[5] The scenarios are not meant to be predictions of the future, but rather a tool to span significant portions of the possible future military responsibility space.

A following task is to carefully analyse each scenario to create a set of capability requirements. The goals established for each scenario will make demands on specific capabilities from across the capability partition. Detailed scenario analysis results should be available to answer decision-maker enquiries, but initially only reported in aggregate. Capability requirements can be developed using war games, where different operational concepts are utilized in different scenarios. The output from these war games should reveal capabilities needed to "handle" or manage risks in the scenario. Inherent in the scenario analysis is another level of ambition: What does it mean for the nation to be satisfactorily handle a scenario? Often this a subjective matter, judged by military analysts. Applying this approach offers an audit trail that begins with forecasts of the future security environment, includes government guidance, and ends with a set of capability requirements.

[5] An example of this could be that the nation's future studies concludes that a nuclear attack with ICMB's is a real threat, and therefore an ICBM attack scenario is created. But the nation's defence budget and technological base will never be able to create efficient Ballistic Missile Defence (BMD). Then the nation's decision makers must ask: Is this scenario beyond our level of ambition, or can this threat be mitigated otherwise?

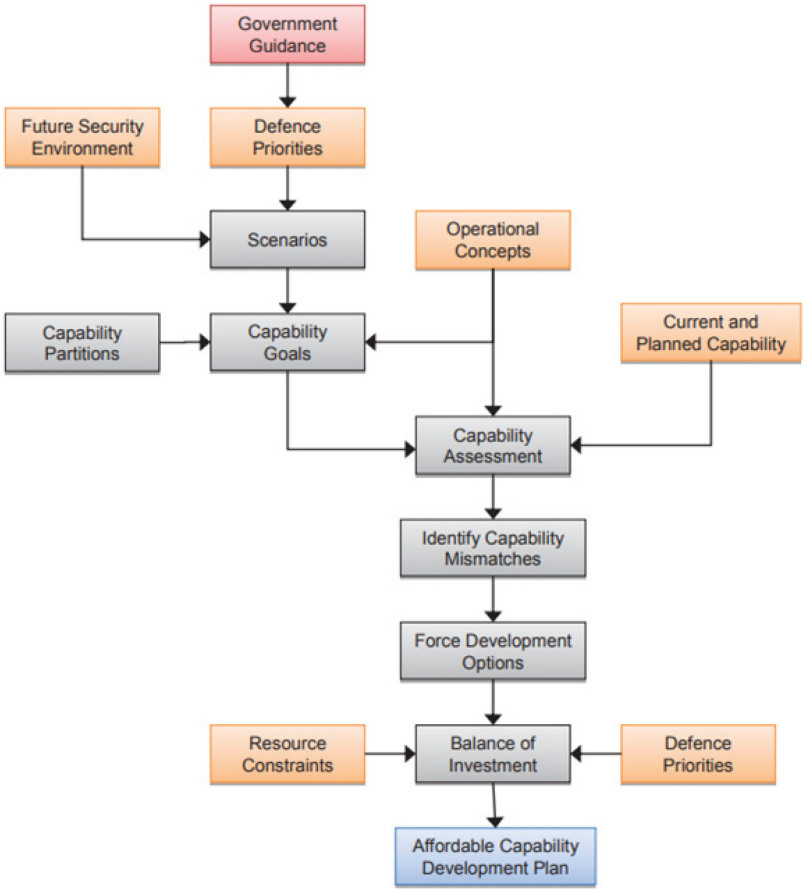


**Figure AA3-1: TTCP Capability-Based Planning Process.[5]**

A task following this is to compare these planned capability requirements with current capabilities in order to conduct a capability gap assessment. This needs to be done in line with the operational concepts mentioned above. In some nations Current and Planned capability is represented by the Future Force (in the UK) or the Force Development Plan (in Norway) from a prior defence planning process. A capability gap assessment identifies capability mismatches.

By developing Force Development Options, alternative force structure elements can be proposed to fill capability gaps.[6] This begins the interface with the investment prioritization problem. This step involves a search for the most cost-effective and efficient physical force unit options to fill capability gaps identified in the CBP. These options need to be well enough designed to ensure successful future implementation of these capabilities.

The final task, which is completed by Planned Investment Portfolio decision makers, is to identify a portfolio that strikes an appropriate Balance of Investment, informed by detailed cost information on the force structure over time, calculated overall funding requirements from the bottom-up like in Norway, or estimated investment costs over time along with maintenance costs in a "normal year" like in Sweden. Whatever the approach taken, the task of generating an affordable capability development plan is the ultimate test of everything coming before it.

[6] If the capability gaps are too large, the nations have to either change operational concepts or reduce level of ambition. A third option is to accept the risk to national security such capability gaps represent and lean on the alliance or partners (which is in practice to lower own nation's level of ambition).

The plan is considered feasible if the estimated total cost over time is below forecasted future budget levels. In reality, this apparently straightforward methodology involves a great deal of technological, financial, analytical, and other challenges. As new capabilities are developed, the threat and operational environment continues to adapt, which might lead to midstream changes in requirements, or other aspects necessary for successful deployment of the capabilities. Similarly, threat and strategy changes can make existing capability levels obsolescent or less effective.

Mandatory requirements to satisfy larger security and defence policy goals should be also addressed. These challenges are made more difficult by a lack of shared knowledge on the part of capability planners as well as armaments program managers regarding technological maturity, technical feasibility, availability, and affordability. This situation makes it difficult to reconcile requirements stated in capability development documents, especially in terms of feasibility and cost. Addressing these knowledge gaps requires a new approach to capability development, where knowledge gained early in the process is injected into the capability development process in a rigorous way.

Most nations have a national security and defence strategy that influences the political level of ambition (what should we be able to do?). National defence organizations translate the level of ambition into military operational requirements (what capabilities do we need to have?). The capability development phase which includes Planned Investment Portfolio decisions involves defence plans, procurement programs, and personnel plans to help fulfil the operational aims (how do we realize the required capabilities?). The operational capabilities of the armed forces are the final outcome of this process.

## AA3.5 Capability Planning and Defence Acquisition

The outcome of capability planning is considered as a basis for directing an effective investment strategy that affordably develops and sustains identified capability priorities. Nevertheless, within the national defence planning processes, the identification of capability priorities is inseparably interconnected with the existing forces' structure. So, in national defence planning, there must be a systematic integration between capability planning and force development. Force development efforts that reflect defined capability requirements not only need to meet strategic objectives, but should also minimize costs, address key risks, and comply with other constraints. The development of an effective force that is able to achieve the expected operational tasks stemming from a given level of ambition, is closely linked to the creation of an affordable and realistic capability development plan, and intimately related to the investment portfolio problem.

Identification of capabilities needed to achieve defined objectives and subsequent development of required capabilities is therefore considered as a key domain of the defence planning process. From this perspective, both processes, i.e., the development of required capabilities and their implementation through DIP financial planning, involve a feedback process that requires ongoing communication, because the interaction is of paramount importance for the successful development and implementation of long-term and medium-term investments plans.

As far as capability-based planning is concerned, many nations have invested considerable efforts to develop suitable tools and techniques to be used to develop those capabilities, which are identified as minimal requirements for achieving a defined level of ambition. For example, Figure AA3-2 illustrates:

- Capability assessment followed by identification of capability shortfalls (gaps) and their military prioritization;
- Searching for affordable options to remedy or mitigate capability shortfalls (providing investment option inputs to the defence investment portfolio problem); and
- Selection of suitable solutions to make up defence investment plans and armament programs (the planned investment portfolio).

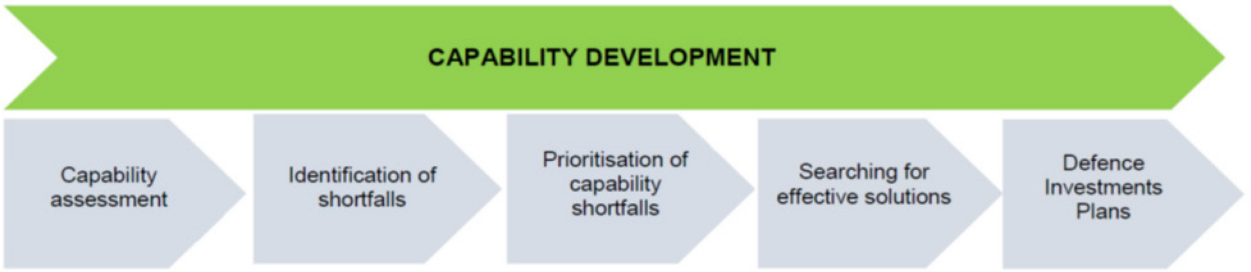


**Figure AA3-2: Capability Development Sequencing.**

The first two steps – determination of capability requirements, and capability assessment (identifying capability gaps and establishing priorities) – are the core of capability-based planning. The next two steps – military prioritization of capability shortfalls and development of cost-effective solutions searching for options to remedy or mitigate capability gaps provide benefit information needed (with cost, budget, and risk information) to select a portfolio of suitable solutions.

Clearly, the determination of capability requirements and capability gap assessment are of the paramount importance[7] for the following steps. The challenge is that investment budgets and other criteria enter into the defence investment prioritization portfolio analysis. These include economic and social concerns (support to national defence industry, and preservation of research and technological base), legal concerns (needs to organize national or even international bidding process, strict budgeting procedures as set up by national government), and other concerns that may complicate the portfolio decision-making process. Without defined and understood regular investment prioritization processes, the process can seem as depicted in Figure AA3-3.

Because the different nations and organizations that conduct defence planning have different systems and aims, the implementation and process are different. Nevertheless, the steps and logic of the CPB-method are all more or less the same in all countries. Defence planning/transformation is often conceived as being divided into two parts: finding out what you need, then implement the decisions. The sometimes forgotten part in the middle is the cost-informed and budget-constrained investment prioritization.

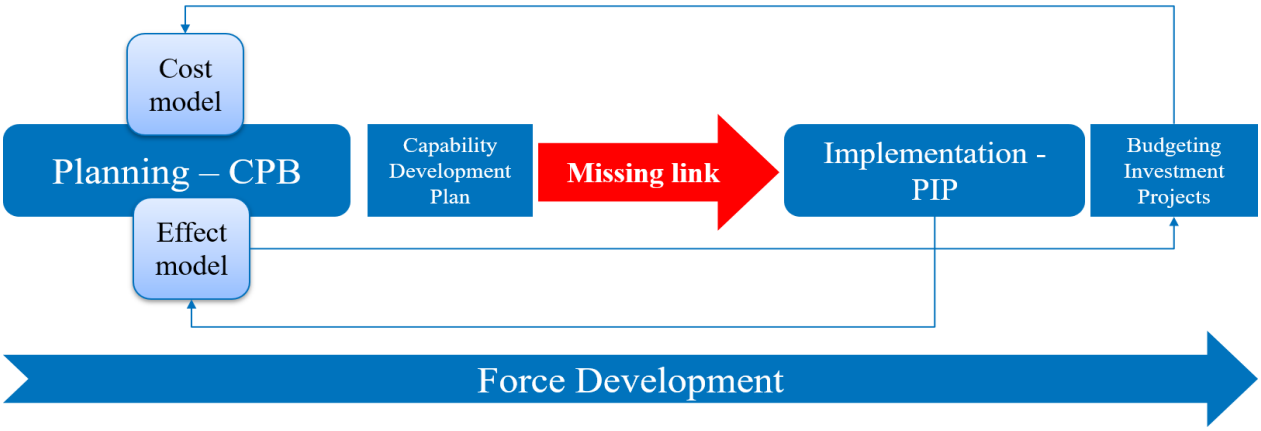


**Figure AA3-3: Interaction Between Force Development and CBP.**

[7] These assessments can be qualitative or quantitative. Efforts must be taken to minimise biases in the design of experiments and wargaming.

The Capability-based planning-methodology is about finding out what you need in line with an affordable level of ambition. The results from CPB are then handed over to the organizations (Army, Navy, AF, etc.) responsible for training and equipping the armed forces to develop the desired capabilities as investments deliver. The defence portfolio problem arises because not all investment proposals can be funded or supported with existing resources, necessitating investment prioritization to ensure military commanders end up with the best affordable mix of capabilities to address current and future threats. So, in this context, capability-based planning cannot be seen as an isolated stand-alone process. It is a necessary step in order to successfully develop a Planned Investment Portfolio (PIP).

## AA3.6 Coexistence of National, NATO and EU Approaches to Defence Planning

Many European countries have the added challenge that their planning process must be aligned with multinational planning systems including NATO and the EU. The NATO Defence Planning Process (NDPP) is the principal vehicle for the synchronization and harmonization of capability development efforts undertaken by Allies [7]. As such, NATO works to increase the coherence of capability development with partner nations and the EU. To this end, NATO continues *"to work closely with the EU to support capability development and interoperability with a view to avoiding unnecessary duplication and maximising cost-effectiveness"* (Ref. [8], p. 1-1).

A complicating factor that reinforces the need for even closer cooperation between NATO and the EU is that 21 nations are members of both, not counting nations, which are not NATO members but also participate in specific NATO partnership programmes. Therefore, all these nations face the additional challenge that their planning processes must be closely integrated with the planning processes of both NATO and the EU.

To complicate matters further, the capability development processes in the EU and NATO are somewhat different. The NDPP is primarily focused on planning and assessing the contributions of allies to NATO forces in the form of assets and capabilities needed to achieve NATO´s Level of Ambition. The key difference between NDPP and the EU´s planning process is in the desired outcome of both planning processes. In the case of the NDPP, it is the implementation of national (or multinational) activities aimed at achieving military capabilities which enable the Alliance to fulfil its level of ambition. In other words, the expected products to be delivered to NATO are national contributions to help meet NATO requirements in terms of assets and capabilities, with a view to successfully conduct NATO-led military operations.

Since many nations use a version of CBP, their capability planning processes are similar to the NDPP. Actually, many national strategic documents refer to the NDPP, although there is no requirement mentioning that the national capability planning should necessarily reflect principles as implemented in the Alliance. Nevertheless, there is a clear requirement that the result from the NDPP,[8] i.e., Capability Targets package assigned for respective NATO nation, should be included in the national capability development process. It is of note that some national security and defence policies that are not necessarily consistent with NATO's common defence and security policy or the EU's common security and defence policy do contribute to some of the diversity and fragmentation observed in national approaches.

One factor that tends to connect national approaches is the procedure under which individual nations are asked to submit their national contributions to NATO and the EU. These national contributions include military assets and capabilities that are a key input for fulfilling expected levels of ambition of both NATO and the EU.

A clear understanding of national contributions required to support NATO/EU capability requirements is therefore critical to establish effective cooperation between national and NATO/EU planners. The key lesson for nations that want to comply with NATO/EU planning procedures, is that they should pay close attention that outputs from their national planning processes are in line with NATO/EU capability requirements.

[8] Step 3 – Apportion requirements and set targets.

Experience shows that there is a huge diversity between nations on how "serious" they are about including NATO/EU capability requirements into their force development process. It is conjectured that small nations more dependent on NATO and the EU may currently be better at doing so than larger nations with broader agendas.

In order to provide more effective integration between national planning processes and the NATO/EU planning process, it is suggested that national planning processes use the same taxonomies as in NATO/EU planning documents.[9] Where possible, national assets and capabilities should also have quantitative and qualitative parameters in line with NATO/EU requirements. This approach would also help support the acquisition and procurement process where it is necessary to clearly specify technical performance parameters of weapon systems and other military equipment.

The enforcement roles of both NATO and the EU are limited when it comes to capability development in their member states. Each nation has its own armed forces, and they develop their armed forces primarily in compliance with their own national security and defence policies, and those do not always completely align with NATO or the EU. However, through the NDPP, NATO nations are held accountable for their performance in realizing their military contributions to NATO assets and capabilities. Moreover, in the CDP, the EU provides guidance to member states on capability priorities. In essence, neither the NDPP nor CDP realize their own capability requirements, but both influence national long-term defence planning processes to fulfil allied capability needs. Afterwards, it is up to nations to decide whether their defence planning process and capability development leads to outcomes enabling them to generate contributions to NATO and the EU that strictly meet identified capability requirements.

## AA3.7 Impact on National Approaches to Capability Development

NATO and EU levels of ambition are different, they have a different context in their historical development and thus they have different security and defence objectives. As for defence objectives, one challenge is how to synthetize priorities, which are often referred to separately, e.g., capability development, financial management, and armaments programmes. Here, the prioritization differs from case to case and from nation to nation – defence financial planning may be supervised by national treasury authorities, armaments program by ministry of industry authorities, etc. Under such circumstances, it is almost impossible to get standardized respective procedures, at the international level.

National capability requirements do not necessarily correspond to those of NATO or the EU (even if there some overlap). Hence, for countries, which are both NATO nations and EU member states, a pressing issue is how to combine national, NATO and EU capability requirements, to provide a solid foundation for defence investment plans resulting from investment prioritization.

Interestingly, the EU focuses primarily on coordinating or directly managing Member States' efforts to implement their own projects and programs to develop national military capabilities. Thus, for the EU, the aim is to help implement a project or program that consists in achieving a required capability primarily identified as necessary from a national (member) perspective. Even if the project/program is implemented to support the EU, the primary goal is to reinforce national capabilities.

The basic principle is to take a bottom-up approach, and build strong national capabilities to be used, if need be, for CSDP purposes. The EU, unlike NATO, has introduced a comprehensive national defence planning process which includes a mechanism for capability requirements identification, monitoring of arms industry

[9] An example of such taxonomy is the NATO capability codes (Bi-SC Capability codes and capability statements, 2016). This is a 400-page list that details capabilities of most kinds. One major issue for analysts trying to use this is the level of detail, which might not be useful for national analyses. The other issue for analysts is that if codes are updated (and they are), then your analysis tools must also be updated. For larger nations with many analysts this might not be a problem, but for nations with 4 analysts able to maintain such tools, it is not cost-effective.

and defence market impacts, defence technology development and research, and which includes financial support for capability development programs.

In summary, many European countries coordinate their planning process to the multinational planning systems of NATO and the EU. This increases the complexity of defence planning and introduces new challenges. The NATO Defence Planning Process (NDPP) is the principal vehicle for the synchronization and harmonization of capability development efforts undertaken by the Allies [7]. As such, NATO works to increase coherence of capability development with partner nations and the EU. To this end, NATO continues "to work closely with the EU to support capability development and interoperability with a view to avoiding unnecessary duplication and maximizing cost-effectiveness" (Ref. [8], p. 1-1).

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# Appendix A.4 – COST ESTIMATION FOR PORTFOLIO PLANNING

Gene Fisher's pioneering paper (1971) reminds us that cost estimation has been a key element in long-term Defence planning for many years [1]. It remains a fundamental component of Planned Investment Portfolio (PIP) decisions. Cost estimation is a prediction of future resource requirements and their monetary values to achieve some purpose, like the acquisition of a new weapon system. It assists in understanding budget limitations and helps determine where scarce resources can best be allocated. Cost estimation remains crucial, particularly because of its ability to provide a universal quantitative measure of the use of resources in monetary terms. Meanwhile, some 50 years later, universal, and widely accepted capability or effectiveness measures remain a work in progress.

In defence, PIP decisions depend on cost estimates that serve a dual function: first, as an integral part of the decision-making process to evaluate military investments, and second, as a baseline for defence budgets [2]. For example, a NATO goal for member nations is to contribute 2% of their GDP to defence, and 20% of that to defence investments. To apply the latter rule suggests there is a fixed defence investment budget that needs to be allocated among alternative programs to provide the most cost-effective forces/capabilities for national and collective security. This fixed budget approach can be contrasted with another (complementary) approach which starts from the threat environment and determines planned levels of national security and desired capabilities. This requires program cost estimates to fill capability gaps that, when combined with other expenses, generates a budget request to achieve military goals and objectives.

A medium-term expenditure framework that has been adapted by many nations called the "Planning, Programming and Budgeting System" (PPBS) combines these two perspectives: threat driven, and budget-constrained. Programming offers a bridge between the two and, according to Melese et al. can be thought of as a constrained optimization where capability investments and operating decisions are made to maximize national security subject to fiscal constraints [2] (p. 364). To perform budget-constrained optimization requires accurate cost estimates for each candidate investment. In turn this requires systems and policies to carefully define, collect and analyse data. Ideally this would involve a network-enabled data system to collect actual cost information in conventional data formats (data bases); to maintain the quality and curation of this data used to prepare cost estimates; and to store this data and make it easily available for use and updating. It is therefore beneficial to have generally accepted and well documented standards. One such standard is ISO 10303-239 which has been put forward by NATO to be adopted as a STANAG [3]. Since planners and government advisers need to understand the total cost of ownership, data systems are needed to support cost estimates not just of capital (equipment, infrastructure, etc.), but also sustainment (operations and maintenance), workforce (military, civilian, contractors, etc.), and other required resources. This concept of *total ownership* (or system) costs necessarily includes *life-cycle costs*.

As budgets are annual and defence planning involves multi-year outlays, estimating the timing/phasing of costs over an investment's life cycle requires other important considerations. First, since politicians are responsible for producing annual budgets and face frequent re-election, they naturally focus on up-front (current fiscal year) costs and tend to discount future costs. Second, future governments may or may not commit to fully fund investments over their life cycles. Third, if two candidate investments generate similar benefits over time, but have different cost profiles, then decision makers may consider the time value of money and discount future costs. (e.g., see Chap 17 in Melese, et al. [2]) Since current interest rates in member countries are low or near-zero, today the latter may not be a major issue.

Another important question in cost estimation involves the scope of the analysis: which costs should be included in the estimate? Whereas to build a budget request all relevant costs need to be included, decision makers choosing among alternative investments can focus exclusively on those costs that differentiate the alternatives, and the time profile of those costs. Ideally, the focus should be on future and not past or ("sunk") costs. An unfortunate reality is that sunk costs often influence decisions when prior spending is tied

to reputations, or when cancelling programs (divestment) after having spent significant funds involves political costs. One lesson related to sunk costs is to avoid "throwing good money after bad."

## AA4.1 The Scope of Cost Estimates in Portfolio Planning

Which categories of defence resources and costs to include in a cost estimate depends on the decision situation. For example, high-level ("globally optimal") investment portfolio decisions taken by a Minister of Defence may differ considerably from those facing an individual service secretary (Army, Navy, and Air Force) choosing among alternatives to fill a capability gap or to replace a legacy weapon system. Moreover, challenges facing lower levels often include constraints generated by higher level considerations, for example, restrictions on available military personnel, or on the construction of new facilities.

Note that when smaller allied and partnership countries procure major weapon systems directly from larger nations (Military off-the-Shelf, MOTS), cost estimation can turn into a market research problem, including forecasting best and final vendor bids/prices. Even larger nations are now considering offloading performance, cost and schedule risks onto defence contractors who own and operate major equipment. This typically involves multi-year lease/rental or other agreements on anything from Helicopter pilot training [4] and military housing [5] to air tanker refuelers [6].

Three basic approaches are typically used in cost estimating:

1) Analogy (using costs of similar systems),
2) Parametric (using generalized relationships between specific system characteristics and costs), and
3) Engineering (bottom-up or industrial engineering analysis) [7].

The accuracy of a cost estimate depends on the amount of information available about the system. The greater the information available, the more precise methods that can be used, the more accurate the cost estimates. In early stages of development, only rough estimates are available for the system parameters and attributes; therefore, only the highest levels of the Cost Breakdown Structure (CBS) can be estimated using "rough order of magnitude" or "top-down" techniques such as analogy and parametric approaches (Ref. [7], p. 117). An interesting example of a parametric cost estimate is offered by Pugh [8]. Based simply on weapon type, predicted in-service date, and weight, Pugh generates estimates that rely on several large nation's extensive databases based including data collected on 4000 weapons systems development projects.

Total ownership cost estimates for a single weapon system are typically presented as Life-Cycle Costs (LCC) that include investment (R&D and production) costs, operating and support (maintenance/ sustainment) costs, and decommissioning/disposal costs (or offsetting benefits in case of a possible future sale). Forecasted outlays should also include consideration of supporting systems and facilities, human resources, program management, and anticipated future upgrades/modifications. See NATO's SAS-054 (June 2007) report for a review of cost forecasting methods and models together with examples that offer a comprehensive guide in the application of life-cycle costing with a focus on multinational programmes. The report recommends the use of multiple approaches whenever possible, conducting regular cost-benefit analyses to ensure there is sufficient value-added.

With a more integrated and connected military force, the posture and readiness of any force package (or collection of systems) required to deliver military power increasingly needs to be considered in decision making. Although identifying substitute systems generally means that lower cost systems can be included in portfolio, multiple substitute (backup) systems might be required for redundancy (to generate more confidence/performance i.e., reliability, availability, etc.), increasing estimated costs. Similarly, complementary systems which generate more performance when combined than they do individually, may or may not result in joint cost savings.

Due to the periodic nature of PIP decisions, investments selected to be included in the current fiscal year enter, may not immediately be operationally available. Long lead times required for complex systems mean that some investments in early development or engineering phases may not provide operational capability until many years later, although they could remain in service for extended periods. This suggests that current investment decisions will be subjected to uncertain future budgets and changes in capability needs that need to be reconsidered in future PIP rounds. Moreover, given shrinking product life cycles, it may become necessary to plan for regular (spiral) upgrades, and shorter and more flexible contracting agreements.

## AA4.2 Budgeting, Project Management and Uncertainty of Cost Estimates

Uncertainty regarding future budgets, future threats, and technological developments play a key role in PIP decisions. Even though there is a need for accurate cost estimates for budgeting as well as to choose among investment alternatives, the issue of uncertainty needs to be addressed. For example, there may be significant uncertainty involved in estimating future resource requirements and their costs for a capability that will be fielded beyond the medium-term expenditure plan. Uncertainty is steadily reduced as the project or program proceeds and as more design, procurement and resource commitment decisions are made. Or as a U.S. Government Accountability Office (GAO) report puts it: *"Cost estimates tend to become more certain as actual costs begin to replace earlier estimates"* (Ref. [9], p. 36). For example, Turner (1999) found that uncertainty of cost estimates in construction projects very early on in the pre-feasibility study phase were in the ± 50 % range, and even after completion of feasibility studies stood at ± 20 %, only reaching a more precise ± 5 % range at the basic engineering phase [10].

NATO has identified some common risk categories in defence acquisition programmes (Ref. [11], p. 2-11). These include:

- **Technical risks –** that may prevent an end item from meeting performance expectations.
- **Programmatic risks –** non-technical risks that are generally within the influence of the program, including making estimates and programme management.
- **External Business risks –** non-technical risks that are generally outside the influence of the program, such as regulations, suppliers, funding and even weather, strikes and other such risks.

Because there are programmatic risks i.e., the project may be managed well or maybe not that well, there are also the management systems inspired by Drucker's Management by Objectives in the 1950s. Project management is tasked with cost, performance and schedule goals and their task is to manage the project to achieve these goals. Management compensation and bonuses can be aligned with a probability distribution of cost and schedule targets rather easily, even though separating programmatic risk from technical and external risks is nearly impossible in practice. However, there seems to be no practical way at the end of the feasibility study stage, where go-ahead decision is taken, to give the project management a budget that would be other than a fixed figure and that would more closely reflect the underlying true uncertainty. This goes also for the governmental cost controls involving budget appropriations that stem from a tradition long preceding that of Drucker's Management by Objectives.

Cost estimating is a continuous process. As more/better information becomes available, it involves continually updating estimates with actual data, revising estimates to reflect any significant changes in assumptions, and analysing differences between estimated and actual costs.

Whereas uncertainty involving program cost estimates is an unfortunate reality, it is scarcely recognized by public sector budgetary controls that take the form of fixed appropriations in a given time frame (generally a fiscal year). For instance, the procurement of a major weapon system with uncertain future costs nevertheless involves a fixed budget appropriation. The challenge is that budget appropriations are deterministic whereas

cost estimates are stochastic. Unless contingency funds are set aside to cover the risk of cost overruns, if it turns out more funds are required, this situation is often handled through a supplemental request for additional funding.

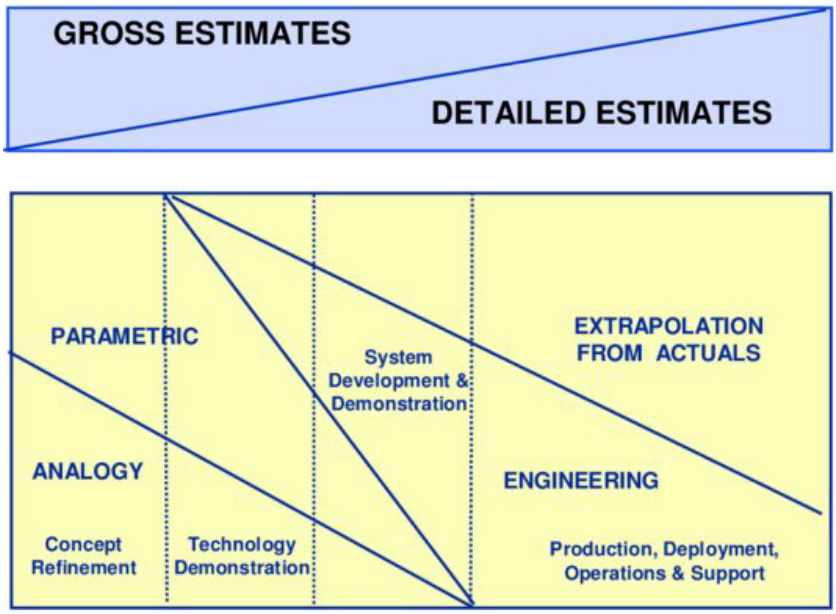


**Figure AA4-1: Use of Cost Estimating Methodologies by Phase. (Ref. [12], p. 3-12).**

As the probability of cost overruns depends on how much money is programmed in the budget, Angelis and Nussbaum (Ref. [7], p. 128) claim the real question is: How much money should be included in the budget to guarantee sufficient funding? For example, how big a budget would give us 80% confidence we can meet future funding requirements for the program, or only a 20% risk of a cost overrun?

Interestingly, a section of the U.S. Weapon Systems Acquisition Reform Act (Public Law 111-23 May 22, 2009) entitled "Disclosure of Confidence Levels for Baseline Estimates of Major Defense Acquisition Programs" [13] directs disclosure of: "[T]he confidence level used in establishing a cost estimate for a major defence acquisition program or major automated information system program, the rationale for selecting such confidence level, and, if such confidence level is less than 80 percent, the justification for selecting a confidence level of less than 80 percent."

Although budgeting at 80% or more confidence lowers the risk of a cost overrun to 20% or less, this increases other risks:

1) That other parts of the portfolio cannot be fully funded or that schedules must be delayed stretching out programs, ultimately resulting in higher unit costs;
2) That it lowers the incentive to control costs, and/or
3) That there is a greater probability that inefficient, end-of-year reprogramming will be required to redistribute **excess** funds.

## AA4.3 Incentive Issues in Cost Estimation

Significant cost overruns in major weapons systems have long been recognized (Ref. [2], p. 358). Today there is mounting evidence that a systematic bias in initial cost estimates of new weapon systems is contributing cost overruns (Ref. [2], p. 358). Arena et al. report based on 46 observations of US Air Force

acquisition programs that in the end, the cost exceeded on average milestone II cost estimate by 46% [14]. Neither is this entirely an U.S. issue as according to an UK Report "*Across a large range of programmes ... the average increase in cost of 40 %... from initial approval to in service dates*" (Ref. [15], p. 7). More recently, Lorell et al. (2015) give in-depth case summaries of six defence acquisition projects that ended up exceeding their cost estimates by factor of two or more [16]. They see that these extreme cost increases were caused by too early approval (immature technology, unclear requirements and unrealistic cost estimates) and management issues (e.g., poor risk management and lack of oversight).

Underestimating costs is not unique to defence acquisition. Flyvbjerg et al. (2002) has studied 248 large infrastructure construction projects and found that at decision stage, costs are underestimated in almost 9 out of 10 projects and that this has been ongoing globally for the past 70 years with no improvement [17].

Two factors commonly used to explain "unrealistic cost estimates" are bad incentives (due to optimism bias) or strategic misrepresentation of budgets (political-economic explanation), and bad estimates (imperfect forecasting techniques) (Ref. [7], p. 130). While a "customer" paying for an investment with their budget would like to set very ambitious targets and get more for less, the project management team ("supplier") would like the opposite, excess funds to guarantee they can cover any unplanned contingencies. Incentives matter. The Gray Report suggests: *"Armed Forces, competing for scarce funding, quite naturally seek to secure the largest share of resources for their own needs, and have a systematic incentive to underestimate the likely cost of equipment"* and, *"Simply put, many participants in the procurement system have a vested interest in optimistically mis-estimating the outcome"* (Ref. [15], p. 6, 19).

Flyvberg (2002) maintains cost overruns are so large and common because the project managers don't have incentives to produces best cost estimates but underestimate them in order to get projects started [17]. What he doesn't mention is that cost estimates could be produced by an independent body (independent cost estimators) with no vested interests in the project. The shortcoming of this solution is that such an independent body cannot, especially concerning complex military weapons acquisition programs, be as well informed about the capability needs and details of designs required to meet them than the project managers. A review of the UK acquisition system concluded that *"Unfortunately the current system is not able to flush out at an early stage the real costs of this equipment, nor does it make effective prioritisation or rationalisation decisions. ... When this over-large and inflating programme meets the hard cash planning totals that the MoD can spend each year, the Department is left with no choice but to slow down its rate of spend on programmes across the board. The result is that programmes take significantly longer than originally estimated"* (Ref. [15], p.6).

In conclusion, many factors besides optimism bias can explain the gap between estimated and actual costs. Technical difficulties may arise, schedules may slip, assumptions may prove false, data may be missing, missions can change, or proposed investments may turn out not to meet the needs of future war-fighters. There is simply no substitute for taking the time and effort to understand the technical, programmatic, and external risks and challenges in developing and producing cost estimates for planned investment portfolios. The payoff includes better budget estimates, and better investment decisions leading to more affordable and effective defence programs with which to guarantee our national and collective security.

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# Annex B – LITERATURE STREAM SUMMARIES

# Appendix B.1: INSIGHTS FOR DEFENCE CAPITAL INVESTMENT PORTFOLIO DECISIONS FROM THE FINANCIAL LITERATURE

## BA1.1 Introduction

The term "portfolio" traditionally refers to financial investment decisions. For example, a stock analyst might search for an optimal mix of stocks to include in a portfolio that fits within a client's budget, with the objective of maximizing returns over a given period with acceptable risk. Defence decision makers face a similar challenge – searching for the optimal mix of investments (weapon systems, projects, programs, etc.) to include in a portfolio that contributes capabilities to maximize national security (or minimize risks) over time, that fits within current and projected budgets, and other resource constraints (personnel, infrastructure, etc.).

Financial market decisions mostly involve benefits that can be monetized (future stock prices, revenues, profits, etc.). The military does not have that luxury. Whereas costs of military investments can generally be monetized, benefits cannot. In contrast to stock market portfolios where the value of a candidate stock to include in a portfolio can be estimated using daily closing prices, finding quantifiable value/benefit data for military investments is a challenge.

For example, even if a candidate investment (say new monitoring software) can be shown to contribute to a capability (like cyber security) that reduces capability gaps to improve readiness and foreign engagement, those benefits are difficult to quantify. This is especially true when an investment takes time to implement and generates benefits over multiple periods. Since market-determined benefit values are not available to help evaluate candidate investments in defence portfolios, non-monetary estimates must be used.[1]

Complicating matters, defence benefits often depend on potentially conflicting objectives of multiple stakeholders, for example: NATO, Parliaments, Presidents, military leaders, etc. Another problem is that even where non-monetary values/benefits can be approximated, they are not uniform across investments. Each investment included in a portfolio should help provide capabilities that support some military strategic goals. Developing universal measures from the unique non-monetary values/benefits of each candidate investment included in a defence portfolio remains a challenge.

The problem is even more challenging when benefits of one candidate investment depends on others. In the presence of multiple objectives, multiple resource constraints, and/or inter-dependent investment outcomes, there is generally no single analytical tool available to help identify the best mix of investments to include in a portfolio. The current study offers a variety of approaches to help address these issues. Even though this makes the defence portfolio problem very different from financial portfolio problems, the financial literature briefly reviewed in this appendix offers some useful insights.

The financial literature generally falls into three broad categories: Net Present Value (NPV) models, Modern Portfolio Theory (MPT), and Real Options Analysis (ROA). The conventional financial literature recognizes money is worth more sooner rather than later and proposes building portfolios to include stocks or business investments that generate the greatest discounted Net Present Value (NPV). Recognizing the uncertainty of future returns on investments, Modern Portfolio Theory (MPT) offers ways to build portfolios in terms of both risks and returns. More recently, the literature on Real Options Analysis (ROA) recognizes the value of deferred decisions and proposes building portfolios that include options to continue, expand, contract, or abandon investment alternatives.

[1] For example, see Chap 8 [1] in Melese et al. (2015) Military Cost-Benefit Analysis: Theory and Practice [2].

## BA1.2 Net Present Value (NPV)

Most financial models tend to reduce multi-period outcomes to a single discounted present value. Recognizing the time value of money, discounting treats present monetary benefits as more valuable than future benefits. The reason is that money today can be placed in relatively risk-free capital market assets that generate future returns.

Businesses and the military both face the challenges of building their investment portfolios. For businesses, the NPV of a candidate investment is simply the sum of the discounted present values of future benefits (cash flows), less the investment costs.[2] The cost of development, acquisition, and operation of an investment is deducted from the present value of cash flows each period (revenues-costs=cash flows or profits) to generate the NPV. Investments with a positive NPV are considered viable candidates to include in a portfolio.

Traditional business portfolio decisions rank candidate investments according to the largest NPV and select them in descending order until no more positive NPV investments remain. Another approach is to select investments that maximize total NPV while staying within the available budget each period.

A business borrowing rate (e.g., the weighted average cost of capital) is often used to discount future cash flows. Alternatively, the cash flow stream may be discounted at a risk-adjusted discount rate based on perceived project-specific risks, historical firm-specific risks, or overall business risks.

For the military, the discount rate selected to apply to the future costs of a candidate investment can be related to the next best alternative use (or "opportunity cost") of those funds.[3] Typically, the discount rate applied to a stream of costs in the public sector is connected to the government's borrowing costs. A popular approach is to use the interest rate on government-issued bonds that correspond to the period of investment.

The discount rate for future military ***benefits*** is much less intuitive. The military value of a given investment at any point-in-time in the future, depends on its projected effects on capability gaps, the estimated importance (at that point in the future) of those capability gaps, and the likelihood adversaries could or would adapt to those enhanced capabilities. We cannot hope to capture these impacts assigning a constant discount rate over time as is done in simple NPV models. Complicating matters, NPV cannot account for interactions among investment alternatives, which are often particularly important in assessing military benefits. NPV is essentially a deterministic model, in which future costs and benefit outcomes are assumed to be known with certainty, and where cost and benefit measures can be expressed in monetary terms. Since the costs and benefits of proposed investment combinations are often uncertain, this has profound implications for portfolio selection decisions.

Consider Uncertain Benefits. When investors assess stocks to include in a portfolio, they do not know for certain whether share prices will go up or down, or by how much, or how quickly. When companies consider a candidate investment in their portfolio, they cannot know with certainty how this will contribute to future profits.

Similarly, when the military evaluates major defence acquisition programs to include in a defence portfolio, no one can precisely estimate the future benefits. For example, how much will the program improve the capability to conduct future missions, or improve deterrence – i.e., prevent adversaries from accomplishing their missions?

[2] Similarly, the Internal Rate of Return (IRR) is the implicit discount rate at which the NPV is zero, while a discounted Return On Investment (ROI) can be calculated taking the ratio of NPV divided by the discounted investment costs.

[3] For example, this could include the value/benefits from using the money to improve some other military or government portfolio, or even to reduce the national debt. For a more complete discussion, see Chap 17 in Melese et al. (2015) Military Cost-Benefit Analysis: Theory & Practice [2].

There is also often uncertainty regarding future costs of candidate investments. Because military portfolio decisions are resource constrained, cost uncertainty has a different impact than benefit uncertainty. Whereas uncertain benefits can sometimes be treated using expected values (probabilities of possible outcomes multiplied by monetary or non-monetary values/benefits), cost uncertainty makes it difficult to determine whether a proposed set of investments will be affordable within a specified budget. Each budget period contributes its own resource constraints, which must all be satisfied. Too much of any resource used in any one period can make a portfolio infeasible. Moreover, since prediction intervals for cost uncertainty increase over time, the probability of violating at least one budget constraint also increases over time.[4]

Traditional financial portfolio theory assumes decision makers are (or should be encouraged to be) risk neutral. That is, decision makers should be indifferent between a guaranteed (certain) benefit offering some value/utility, and an uncertain benefit (gamble) that generates the same *expected* value/utility, i.e., on average.[5] The reality is that decision makers often have asymmetric preferences with respect to gains and losses, and thus typically prefer a certain gain, over a gamble with the same expected value.

Attitudes toward risk can be especially complex and inconsistent in the military. For example, decisions seen as putting lives at risk may be made very conservatively, while decisions that put dollars at risk may be made more liberally, revealing stronger preferences for high-risk investments.

In some financial investment models, the benefit of each alternative is its risk-adjusted expected net present value, and the cost is the present value of the future stream of investment costs. The optimal portfolio would invest as much money as possible in the investment with the highest benefit-to-cost ratio, then invest as much as possible of any remaining funds in the investment with the next-highest benefit-to-cost ratio, etc., until all available funds have been invested.

Similarly, the simplest defence portfolio problem could be formulated as the well-known linear knapsack problem where the "greedy heuristic" selects investments in decreasing order of their benefit-cost ratios. This usually produces optimal or near-optimal portfolios, but only if the following conditions hold:

1) The list of available investments is known.
2) The benefit of each candidate investment is known and quantifiable in terms of a universal monetary or non-monetary ("util") value, and costs and benefits of investments are approximately independent of other investments.
3) The cost of each individual candidate investment is small relative to the overall budget.
4) Uncertainty in costs and benefits can be adequately treated using expected values or other "riskless equivalent" valuations.

Unfortunately, for military investments these conditions are rarely if ever satisfied.

### BA1.3 Modern Portfolio Theory (MPT)

To capture the variation in stock prices, Modern Portfolio Theory (MPT) allows investors to set portfolio goals in terms of both risks and returns. The portfolio selection problem seeks to maximize expected returns

[4] Defence planning is a long-term game, and it would not be acceptable to optimize capability over the planning horizon in a manner that leaves future planners stuck with obsolete and poorly-maintained equipment (and nothing new in the pipeline) at the end of the planning horizon. Typically, this is handled by making the strategic planning horizon significantly longer than the portfolio decision cycle, so that the latter portions of the plan are always being supplanted by new portfolio decisions long before those years arrive.

[5] Von Neumann and Morgenstern [3] derive a rule that ranks financial portfolios based on their expected utility that assumes risk neutral decision makers and satisfies several basic consistency axioms.

for a given variance in those returns (risk), or alternatively, to minimize the variance (risk) for a given expected return.[6] Typically, returns are measured as an expected NPV.

MPT was a major leap forward in the financial literature, in that it explicitly accounts for interactions among investments (through a covariance structure) and treats risk as an explicit stakeholder value. In the stock portfolio example, while expected returns are additive, the variances, or risks, are not. They depend upon the relationship (or correlation) between individual stocks, known as covariance. However, this is still not directly applicable to most business or military portfolio decisions.

The MPT literature primarily focuses on portfolio decisions where the decision maker's objectives can be reduced to a monetary dimension (return) and an uncertainty dimension (risk). For a financial portfolio the stock price represents the market's judgment of the value of the underlying company, and the stock's variation over time, the risk. Similar data is available for every candidate stock under consideration for a portfolio. Moreover, MPT assumes: i) each candidate stock is infinitely divisible, such that investors can invest as much or as little at a given expected rate of return; ii) there are no resource limitations on investments, so that any mix is feasible; and iii) interactions among investments can be captured by the covariance of monetary returns.[7]

In sharp contrast, expected defence benefits depend on potentially conflicting objectives of multiple stakeholders. Moreover, even where individual non-monetary values/benefits can be approximated and include investment interactions, they are not uniform across investments. How to develop universal measures from unique non-monetary values/benefits provided by different candidate defence investments remains a challenge.

### BA1.4 Real Options Analysis (ROA)

A call "option" in finance involves paying for the right, but not the obligation, to purchase a stock at a future date.[8] Recent developments in the financial literature attempt to value options on real physical assets. Black and Scholes [5] first developed the theory of option valuation as a model of how prices for commodities options change over time. Their work led not only to an explosion in options trading, but also to an expansion of the theory to other kinds of investment decisions.

Most financial models tend to reduce multi-period outcomes to a single discounted present value. This makes it impossible to model complex time-dependent constraints. Traditional methods such as NPV and MPT treat investment decisions as all-or-nothing. Many financial portfolio models implicitly assume a portfolio is to be chosen once, and evaluated once, both for future benefits and feasibility. They do not account for managerial flexibility that could alter the course of an investment over time when certain aspects of the project's

[6] In 1952, Markowitz [4] developed the concept of mean-variance analysis that would become the basis for what is now called MPT which characterizes investment alternatives by their (probabilistic) rate of return, and by the variance within (and covariance between) returns. Markowitz develops a rule for an efficient portfolio of stocks where expected returns are maintained while variance (risk) is minimized. At its core, the model is based on the concept of diversification, minimizing the variance of the return of a portfolio for a given mean return, or maximizing the return for a given variance. This can be achieved by increasing the number of assets included in the portfolio, diversifying risk over as many assets as possible.

[7] For example, the Capital Asset Pricing Model (CAPM) states that under some simplifying assumptions, the rate of return on any asset may be expected to be equal to the rate of return on a riskless asset plus a premium that is proportional to the asset's risk relative to the market. The assumptions for the CAPM include: investors are risk-averse individuals who maximize their expected utility of their end-of-period wealth; investors are price-takers and have homogeneous beliefs and expectations about asset returns; there exists a risk-free asset, and investors may borrow or lend unlimited amounts at the risk-free rate; the quantities of assets are fixed, and all assets are marketable and perfectly divisible; asset markets are frictionless, and information is costless and available to all investors; and there are no market imperfections like taxes, regulations, or restrictions on short sales.

[8] Note: An *American option* can be exercised at any time before and including the expiration date, whereas a European option can only be exercised on the expiration date.

uncertainty become known. In practice, defence portfolio decisions are often made sequentially, may be revisited, and can be revised or cancelled.

Real options are similar to financial options in providing the right, but not the obligation, to take a specific action in the future. For example, consider a business decision to invest in a candidate project. A real option offers the right to take a certain action at a future point-in-time – for example, starting, expanding, contracting, or cancelling the project. This has led to a large (and growing) literature applying Real Options Analysis (ROA) to project portfolio investments. ROA recognizes the value of delaying decisions and suggests building portfolios that include options to continue, expand, contract, defer, switch, or abandon/divest investment alternatives. Portfolios of real options can be thought of as consisting of combination of multiple risky assets and multiple real options written on these assets, subject to constraints.

While ROA is more general than MPT, it falls short of providing a useful framework for most defence portfolio selection scenarios. The main shortcoming is that, like all financial models, it assumes that expected returns and the riskiness of those returns are the only objectives and makes certain structural assumptions about their time dependence and probabilistic interactions.

In general, it will not be possible to find a value function that incorporates all stakeholder objectives into dimensions that have the same temporal and probabilistic characteristics as financial returns. Another problem is that, as with MPT models, most ROA models are focused on characterizing individual investment alternatives and ranking them, rather than on finding good feasible combinations of simultaneous investments subject to time-phased resource (or other) constraints.

We conclude with an interesting case of a military investment included by the U.S. Army in their defence portfolio. It involves the development of the Javelin anti-tank missile (See Chap 14 [6] in Melese et al. (2015) Military Cost-Benefit Analysis – Theory and Practice [2]). The Javelin required advances in several immature technologies to provide a “fire-and-forget” tracking and guidance system. Instead of investing in a single technology, the U.S. Army paid three contractor teams $30 million each to develop their competing technologies. By spreading the $90 million over the three competitors the Army in effect acquired the right, but not the obligation, to purchase the most successful technology at a later date – a textbook example of a “real option.”

## BA1.5 Conclusion

Defence decision makers face the challenge of finding an optimal mix of investments (weapon systems, projects, programs, etc.) to include in a portfolio that contributes capabilities to maximize national security (or minimize risks) over time, and that fits within current and projected budgets, and other resource constraints (personnel, infrastructure, etc.). Many portfolio models assume binary alternatives – for any candidate investment, you either make that investment or you don’t. Financial models are slightly more general, in that you also need to decide how much money to put into each investment.

Directly applying portfolio theory to government portfolios has been stymied by the lack of a suitable proxy for private sector “stock prices.” Financial and business decisions mostly involve benefits that can be monetized. Meanwhile, although the costs of military investments can generally be monetized, benefits cannot. Moreover, even where non-monetary values/benefits can be approximated, they are not uniform across investments. In the presence of multiple objectives, multiple resource constraints, and/or inter-dependent investment outcomes, no single analytical tool is available to help identify the best mix of investments to include in a portfolio. This study (SAS-134) offers a variety of approaches to help address these issues.

Even though the defence portfolio problem is very different from financial portfolio problems, the financial literature briefly reviewed in this appendix offers helpful insights. Traditional discounted cash flow analysis

assumes investment decision are made initially with no recourse to choose other pathways or options in the future. In contrast, Real Options Analysis (ROA) might be used to more optimally time and spread large risky investments into multiple-stage investment structures. At each stage, defence decision makers would then have an *option to wait* and see what happens, as well as the *option to expand* or *abandon* the investment in subsequent stages. This could result in better informed strategic decisions as various categories of uncertainty are resolved through the passage of time, actions, or events.

Conclusion: applying some combination of approaches discussed in this study can offer valuable guidance. Eight key steps in the process of supporting good portfolio decisions: 1. Framing the problem 2. Identifying and characterizing alternatives 3. Identifying and quantifying outcome attributes 4. Quantifying the value of portfolios 5. Accounting for risk and uncertainty 6. Representing constraints and feasibility 7. Identifying good portfolios 8. Performing sensitivity analysis

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# Appendix B.2: OPERATIONAL RESEARCH

The origins of operations research are generally attributed to resource allocations questions that arose in World War II and this focus remains central to many operations research studies. Hillier and Lieberman define operations research as being "[…] concerned with optimal decision making in, and modelling of, deterministic and probabilistic systems that originate from real life" (Ref. [1], p. 5). This includes structuring problems in a mathematical model, solving the model, and providing recommendations to the decision maker. The definition of operations research is very broad and as such it overlaps with and draws from many other fields. In the interest of distinguishing the term from others used in decision making, we will focus on the most unique portion of operations research, which formulates and solves mathematical optimization problems [1].

From an operations research perspective, portfolio analysis requires a mixed integer program. Some of the items in a portfolio analysis are non-divisible – it is not possible to build 1/3 of a helicopter and receive 1/3 of the benefits associated with the helicopter. Non-divisible items are considered to be integer. Other items, such as manpower are divisible. It is possible to hire someone for half-time and get half of the benefits of having hired them full-time. Because of the presence of both integer and non-integer values in the portfolio, techniques suited to solving to non-integer mathematical problems (such as standard linear programming approaches, ranking and selection by cost-effectiveness ratios, and common heuristics such as selecting all large [or small] projects first) are not suitable to solving resource allocation problems. In fact, integer programming problems are NP-complete making it extremely difficult to find good solutions to them.

One of the most interesting aspects of integer programming is that incremental solutions are most likely not optimal. This means that your optimal choices at one level of a given constraint, such as the budget, may not be in the set of choices at a different (larger or smaller) level. For example, the items that you may choose in your optimal portfolio if you are limited to $100 million may not be in your optimal portfolio of projects if you have $200 million. This is counter-intuitive to many decision makers who have been taught to incrementally augment their budgets and recommend "the next best thing." The reality is that at a larger budget, the best thing to do is scrap several existing choices and do something else entirely.

Many, many textbooks and scholarly articles are devoted to finding good approximation techniques to these types of programs, see for example, Reinelt et al. [2], Papadimitriou and Steiglitz [3], Sierksma, and Zwols [4], or Williams [5]. There is a conference devoted solely to solving these types of problems, the Integer Programming and Combinatorial Optimization conference (IPCO).[9] In addition, much commercial software is available that has programmed one or more of these techniques into a user friendly (more or less) interface with associated consulting companies providing their services. Portfolio analysis is one of the applications of these types of problems, so all of the different techniques may offer a solution methodology, regardless of the initial application studied. Brown et al. (2004) [6] provide concise compilation of defence capital planning variants.

While approximate solution techniques and approximation techniques engender an extremely technical discussion which is decidedly the purview of operations research, all of this assumes that the problem can be set up stating the objective function, the variables, and the constraints. Variables are the choices, the options of what can be potentially included in the portfolio. Constraints are the limits that are imposed on the problem. The most common of these are resource constraints, such as the budget, personnel, or processing limitations. Other constraints can focus on capturing interactions between choices such as conditional requirements (if project A is selected, project B must also be chosen – for example if a particular satellite is chosen, the needed supporting activities such as launch systems and electronic monitoring systems must also be chosen) and incompatibilities (if project A is selected, project C can no longer be chosen for example, if a specific type of electronics is chosen, all systems that would cause interference with that need to be

[9] http://www.mathopt.org/?nav=ipco.

disallowed). Yet other constraints can be imposed based on strategic requirements (at least one base in a given region must remain operational) or total portfolio level requirements (a certain amount of surveillance coverage must be provided). Some constraints are relatively easy to develop while others remain extremely difficult to create. There is still much debate over practical and complete ways to include measures of risk into a portfolio both at the component level and at the overall portfolio level.

The objective function is arguably the hardest element of the mathematical model to develop. Operations research tends to assume that the objective function exists in a relatively simple to capture (preferably additive) mathematical form. It usually does not exist a priori and developing a complete and appropriate objective function that properly reflects a decision maker's choice has become the domain of study of Decision Analysis, discussed in the following section.

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# Appendix B.3: SYSTEMS ANALYSIS

The post-war literature on Defence Investment Prioritization (DIP) grew out of lessons learned in WWII. This includes the development of "systems analysis" which emerged as a best practice, along with the introduction of the "Planning, Programming and Budgeting System" (PPBS). These two developments provide an analytical foundation that continues to guide defence investment decisions in the United States, and in most NATO and partner countries.

Developed by Ed Paxson and Charles Hitch in 1948 at the RAND Corporation, systems analysis is based on techniques that combined economics, statistics, operations research, and decision theory to help win the war. Operations research had a more immediate focus, for example finding the best solution to a military mission, given limited equipment, supplies, personnel, etc. In contrast systems analysis was more future-oriented. It represents an early attempt at portfolio optimization, using techniques such as cost-benefit analysis to find the optimal mix of forces, equipment, supplies, personnel, etc. necessary to accomplish a military goal at the lowest possible cost, or alternatively, for a given budget, to find the optimal mix that maximizes defence capabilities.

Private companies face similar challenges. In a study on weapon system acquisitions entitled "Opportunities Exist to Improve the DoD's Portfolio Management," the Government Accountability Office reviewed the portfolio management approaches of several US companies [1]. They conclude "companies establish a strategy that lays out the overall goals, objectives, and direction for the company, identify and define market opportunities, and then prioritize those opportunities within resource constraints." Moreover, "once companies have identified and prioritized their market opportunities, they follow a disciplined process to assess the costs, benefits, and risks of potential product [investments] and allocate resources to achieve a balanced portfolio that spreads risk [and that] aligns with the company's strategic goals and objectives [to] maximizes the company's return on investment."[10] However, companies have an important advantage over Ministries of Defence. The benefits of their alternative investment portfolios are easily monetized. A significant challenge in defence decisions is the complex and often controversial task of measuring "benefits." A related literature, reviewed in a later section of this report, rapidly evolved after WWII to address this challenge. Alternately called Multi-Criteria Decision Making (MCDM) or Multi-Objective Decision-Making (MODM), this literature tackles the thorny problem of evaluating defence investments when benefits cannot be monetized. For example, see Melese, et al. [2], etc.

Working at RAND in the immediate post-war era, Charles Hitch teamed with another economist, Roland McKean, to publish a pioneering text entitled "The Economics of Defense in the Nuclear Age" [3]. The authors emphasize two key goals for systems analysis: i) to guide defence policy (i.e., the allocation of resources between major military missions) and ii) to guide defence investments (i.e., choices between alternative projects or programs to achieve those missions). The Planning, Programming, and Budgeting System (PPBS) developed by Hitch and his team at RAND represents an integrated framework that incorporates systems analysis to achieve both.

The first three steps in NATO's Defence Planning Process (1. Establish Political Guidance, 2. Determine Requirements, and 3. Apportion Requirements and Set Targets) reflect the Planning and Programming phases of PPBS. "Planning" involves assessing current and future threats and identifying capabilities to deter/defeat those threats. "Programming" involves the application of systems analysis to make multi-year portfolio investment decisions to build force structures that provide capabilities to address the threats. "Budgeting" simply translates those decisions into an annual budget submitted to Ministries of Finance for review by Parliaments/Congress.

[10] An important lesson is to "avoid committing to more programs than their resources can support and ensure stability in the programs they invest in." Companies also "emphasized that making tough go/no-go decisions is critical to keeping a balanced portfolio."

Following John F. Kennedy's election as President in 1960, newly appointed Secretary of Defense Robert McNamara hired Charles Hitch to implement PPBS. Prior to Hitch's introduction of PPBS, individual military departments (Army, Navy, Air Force) largely prepared their budgets independently of one another. Each individual department requested annual incremental increases in their inputs/appropriations (e.g., Military Personnel, Procurement, Operations & Maintenance, Military Construction, etc.), often with no clear connection to overall defence readiness, joint or combined missions, or other national security goals. There was duplication (President Eisenhower said "triplification") of effort, and little analytical basis on which to make choices among competing proposals. Each department felt entitled to a fixed share of the budget regardless of the impact of their programs on overall defence requirements.

The development of PPBS was intended to facilitate planned investment portfolio decisions. It "set forth certain major objectives, to define programs essential to these goals, to identify resources to the specific types of objectives, and to systematically analyse the alternatives available" [4]. In 1961 Secretary of Defense McNamara created an analytical organization called the "Office of Systems Analysis" to review service proposals and evaluate alternatives. Staffed with civilian analysts (so-called "whiz kids"), it was tasked to independently assess service program proposals and budget requests in order to build an overall defence portfolio. The responsibility for portfolio investment prioritization evolved into an organization known as Policy Analysis & Evaluation (PA&E), that today is called Cost Assessment and Program Evaluation (CAPE).

A major innovation of PPBS was a multi-year "programming" phase intended to bridge the gap between long-term military planning and annual defence budgets. Designed as a constrained optimization underpinned by systems analysis, "programming" requires a clear set of defence goals and objectives to guide Portfolio Investment Prioritization (PIP) decisions. The goal of multi-year "programming" is to build and maintain a cost-effective mix of forces that maximizes national security subject to forecasted budget constraints.

In his classic article "The Road to PPB" [5], Allen Schick emphasizes that PPBS integrates three key budgeting perspectives: Planning (What to do?) and Programming (How to do it?) which involves an outcome/output or "management" focus on the Best Use of Funds, and Budgeting which has an input/accounting or "control" focus on the Legal Use of Funds. Novick's definition of Management closely resembles the portfolio investment prioritization problem: "[It] involves the programming of approved goals into specific projects and activities…" (p. 244).

In most countries politics drives the defence budget process to focus almost exclusively on the next budget year. Yet current defence investment decisions have significant impacts on future budgets. The planning phase of PPBS was intended to provide a long-term, multi-year overview of the defence environment to guide portfolio investment decisions in the programming phase. The programming phase has a shorter multi-year perspective, while the budgeting phase is limited to accurately pricing the first year of defence portfolio investment decisions and other expenditures developed in the programming phase. Similarly, NATO's Defence Planning Process (NDPP) has a four-year cycle that focuses on the short term (0 – 6 years), the medium term (7 – 19 years), and the long term (20+) years.

An effective portfolio decision support methodology for defence applications needs to account for multiple stakeholders or "decision makers." This raises the possibility, and even likelihood, that multiple conflicting objectives are represented. PPBS was developed to help meet this challenge and find the best consensus solutions or compromises. Another important challenge in portfolio investment decisions is that every decision to include a specific project or program has a direct cost, but also an indirect "opportunity" cost. This involves the next best alternative investment sacrificed, which can be measured in terms of lost capability.

Finally, it is important to anticipate the impact of portfolio investment decisions on the future threat environment. A recent example is the rise of asymmetric and cyber warfare in opposition to defence portfolios that include high cost and technologically advanced weapon systems. Since defence involves interactive decisions between a country and its adversaries, it could pay to "Red Team" a nation's portfolio investment decisions.

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# Appendix B.4: HUMAN BIAS – INDIVIDUAL AND GROUP

Human capacity to understand complexity is limited. When confronted with complex situations, we often cope by over-simplifying, and the quality of our decisions suffers. Having to allocate limited resources between programs triggers specific biases. When multiple stakeholders assemble to decide, these biases can mix with the group culture to create group biases that are difficult to counter. This appendix deals with each of these in turn.

## BA4.1 Individual Biases

Psychologists studying how human beings deal with situations beyond their ability to comprehend have observed coping patterns called heuristics that generate a simple but distorted understanding of the situation, which motivates inferior choices. Table BA4-1, summarized from Chapter 10 of Spetzler et al. (2016) [1], describes the most common individual biases grouped by their drivers, with strategies to counter them included in parentheses.

**Table BA4-1: Common Individual Biases Grouped by their Drivers (with Strategies to Counter them).**

| Driver (and its Cure) | Specific Bias | Description |
|---|---|---|
| Protection of Mindset (Habitual testing of own beliefs against experience and new information, deliberate red-teaming) | Avoiding dissonance | Unconscious discrediting of information that conflicts with one's own beliefs and worldview |
| | Confirmation bias | Unconscious validation of information that reinforces beliefs and worldview |
| | Overconfidence | Overestimation of personal knowledge of the future |
| | Hindsight bias | Memories that omit aspects of personal uncertainty |
| | Self-serving bias | Attributing success to personal efforts, failure to circumstances |
| | Status quo | Reluctance to acknowledge the need to change |
| | Sunk cost | Past investment warrants continued investment |
| Personality and Habits (Consciousness of one's own, practice of their counterparts, focus on situation needs) | Preference-based habits | Ascribing importance and merit, respectively, to what one most readily notices and prefers. |
| | Habitual frames | Preferring to include or exclude related issues, factors |
| | Content selectivity | Emphasizing issues and factors to which one is attuned |
| | Decision styles | Personality-based degree and type of deliberation, consideration and deciding |

| Driver (and its Cure) | | Specific Bias | Description |
|---|---|---|---|
| Faulty reasoning (tool-supported analyses of preference, probability) | Complexity | Selective attention | Ignoring what seems less important |
| | | Over-simplification | Relevant features dropped from all consideration |
| | | Substitution heuristic | Replacing a difficult problem/question with a related easier one |
| | | Order effects | Ignoring what came after (or before) |
| | Uncertainty | Confusion about uncertainty | Erroneous thinking about joint probabilities |
| Automatic Associations (Review judgements to identify how they were reached) | | Ease of recall | Associating importance or likelihood with ease of recall |
| | | Availability effects | E.g., new info is more important than old info |
| | | Vividness | Elevating the importance of memorable instances |
| | | Narrative fallacy | A story explaining what is known hiding information gaps |
| | | Halo effects | Features of an event extended to people/things nearby |
| | | Anchoring effects | Fixation on early information amid uncertainty |
| Relative Thinking (Identify standards used to make judgements) | | Framing effects | Preferences affected by how solutions are described |
| | | Reference point effects | Preferences affected by the standards to which they are compared |
| | | Context effects | Preferences affected by included irrelevant items |
| Social Influences (Cultivate skills of independent thought and voiced opinion) | | Conformity | Suppression of thoughts/ideas not shared by others |
| | | Suggestibility | Acceptance of thoughts/ideas shared by others |
| | | Cascades | Treatment of thoughts/ideas according to trend |
| | | Groupthink | Social discouragement of diverse views |

### BA4.2 Resource Allocation Biases

In addition to these intrinsically human and social phenomena, the nature of the investment prioritization problem can trigger specific biases. These biases derive from heuristics that humans commonly use to allocate, but they tend to support options that diverge from achieving the most benefit from the resources available, which more expert decision makers would reject [2].

## BA4.3 Group Decision Mega-Biases

The intent for group decision making is that individual knowledge, skills, and values combine to generate shared insight into decision alternatives and shared commitment toward the strongest courses of action. However, apart from their distinct domains of expertise and interests in the decision, social influences between them can trigger individual biases, which interact according to the culture and leadership of the group to create specific group biases. Spetzler et al. [1] call these mega-biases because, being rooted in a shared culture, they can be very difficult to effectively counteract.

### BA4.3.1 Overly-Narrow Framing

The most common of the value-destructive decision faults is narrow framing. It occurs when there is too little recognition of the nature of the problems to be addressed, leaving valuable decision objectives, considerations, and possibly conflicting assumptions unidentified and unreconciled. Two variants of this problem are:

1) Frame blindness, where an "action bias" causes the decision frame to be taken as first presented; and
2) Lack of frame control, where a single perspective dominates problem definition and assumptions.

In both cases, how well the frame sets up the decision to achieve a good outcome is not considered [3].

Symptoms of overly-narrow framing include treating unsupported assumptions as though they were facts, preferring alternatives that promise quick results and seizing hold of information that reinforces unexamined assumptions (confirmation bias).

### BA4.3.2 The Agreement Trap

The agreement trap occurs when decision makers assume that apparent agreement is a sign that they have arrived at the best decision. Agreement can be a purely social phenomenon whenever standing out involves risks of humiliation or other personal cost, where there is pressure to conform or when people want to seem to be a "team player." When decisions need to involve others, premature agreement drains the value of their participation and undermines decision quality, wasting everyone's time.

Once true decision quality (see Appendix B.6) has been achieved and a decision must be implemented, agreement is valuable and necessary but before that point, disagreement is a necessary driver in sound group decision processes. It is essential to a fully informed evaluation of alternative strengths and weaknesses.

Understanding decision quality helps decision makers recognize when agreement is premature. Preventing the agreement trap from interfering with decision quality requires leadership to recognize their part in establishing social dynamics, highlighting the value decision makers need from team players and eliciting the issues that have not been brought forward with techniques that reduce the social risks of contributing to the decision.

### BA4.3.3 The Illusion of Decision Quality

Decision groups can succumb to the illusion of decision quality when they make their assessments in a rushed and unconsidered way. Spetzler (2011) calls it "the biggest bias of all" [4]. It is driven by "Protection of mindset" biases and the natural reluctance to honestly self-evaluate in a group.

Decision quality evaluation requires mentally stepping outside the process and social considerations to consider the attributes of excellence in each decision dimension and entertaining the possibility that more could be done to improve them. Then, the scale of available benefit and the cost of pursuing that it can underpin realistic quality assessments.

### BA4.3.4 Comfort Zone

The comfort zone bias is a particular framing error that occurs when decision makers react to the uncomfortable complexity of the real problem by reframing it as a related problem, they feel capable of solving, rather than acknowledging the real challenge and seeking the expertise of others to meet it. They redefine the difficult problem into an easier, cartoon version.[11]

Addressing the comfort zone bias requires courage to survey the nature of the problem. Relevant dimensions to explore include:

1) Content expertise (Do the relevant topics require specialist input?);
2) Analytical complexity (Will decision insights require uncommon techniques and tools?);
3) Magnitude of impact (What are the stakes in addressing this situation properly? How well or badly might things go?);
4) Organizational complexity (How many different stakeholders need to buy into the implementation of any decision we reach?); and
5) Likely decision traps (How far away from familiar territory will finding the best decision take us?).

Then, an honest assessment of the demands of the problem can be made, and the necessary time and resources mobilized to address it properly.

### BA4.3.5 Advocacy / Approval Myths

When decision-making processes are built around a conflict event in a competitive organizational culture, it can badly delay successful resolution of significant problems at considerable cost, generating "more heat than light." This occurs where the organization's problem-solving paradigm is to give the problem to a team, in effect saying, "go find the best solution and then present your recommendation for our approval." This sets up an approval event with two roles: the Advocate, who will present the recommended solution to the problem, and the Approver, who will give the thumbs-up or thumbs-down. Thumbs-up leads to implementation, and thumbs-down sends the advocate back to the drawing board to come up with something better.

Underpinning this decision practice are two beliefs:

- **The Advocacy Myth:** A prepared advocate will reveal the best decision alternative.
- **The Approval Myth:** Only a good decision survives hard questions at an approval conference.

There are several problems with this paradigm. First, are the incentives imposed on the advocate, who wants more than anything to get that thumbs-up. The process shifts the objective away from presenting the approach that will deliver the best outcomes and toward leaving the approval authority with no option but to accept the recommendation. This imposes the following criteria on the recommendation:

1) The recommended alternative must be easy to sell, nothing that would raise eyebrows, or provoke scoffing.
2) The advantages of the recommendation must be exaggerated, and the disadvantages minimized.
3) The advantages of all other alternatives must be minimized, and their disadvantages exaggerated.
4) All apparent uncertainty must be banished from the presentation. It will only open up questions that currently have no good answers.

[11] As the old saying goes, *"to someone with a hammer, everything looks more like a nail."*

5) Information that does not support the recommendation must be concealed. (After the "thumbs-up," problems are the responsibility of the approval authority.)

6) Any known biases of the approval authority are to be triggered and exploited, not mitigated.

The situation of the approval authority is hardly any better. The approver has been given no role in the detailed definition of the problem (framing) or generation and evaluation of alternatives. All they have to go on is the carefully selected and presented material. Hence, they must look for and attack any weak points in the performance, sniffing out the expected self-interested deception. Any uneasiness with the results of post-presentation questioning leaving them with only two options: assume the risk of approving a possibly-flawed solution (and take ownership of its faults) or dismiss the recommendation and wait for development of another recommendation. All possibility of approver reflection, innovation in the creation of alternatives from greater experience or review of the entire original information is ruled out.

This badly structured decision process paradigm was quite common in large North American industry in the 1990's. It imposes a particularly heavy burden on "decision intensive" industries, where competitiveness is more heavily influenced by the quality of the decisions taken than by the quality of their execution or operations.

The remedy to the advocacy/approval paradigm is to set a more collaborative decision process as the corporate norm, supported as necessary with Decision Analysis (DA) and facilitation. The Dialogue Decision Process was specifically developed for organizations with strong DA capabilities in-house. (See Appendix B.8 for details.) Decision Conferencing can be used when DA and facilitation is to be provided by contracted consultants. (See Appendix B.7.)

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# Appendix B.5: DECISION ANALYSIS

The discipline of Decision Analysis (DA) is a complement to older decision-making techniques such as systems modelling and operations research. It is unique in its focus on the decision maker, the role of their (and any stakeholders') preferences [1] and on addressing the analytical and organizational complexities that can make good[12] strategic-level decision making so difficult and applying systematic approaches that are able to manage and mitigate [2]. In addition to statistical decision theory, decision analysis draws on psychology, economics, and social science.

Decision Analysis as a named discipline is now more than 50 years old. Previously known as "Applied Decision Theory," in its earliest incarnation, the choice facing a decision maker was expressed as a mathematical function that encoded the uncertainties surrounding a decision and the decision maker's value judgments. The best option was the one with the highest expected utility [3]. Given the difficulty in applying this methodology, numerous improvements and supporting techniques were developed to enhance implementation and to capture more considerations relevant to sound decision making.

The strategy of DA involves:

- Structuring and breaking the decision down into more manageable parts;
- Explicitly considering the possible alternatives, available information, involved uncertainties, and relevant preferences; and
- Combining these to arrive at optimal or "sufficiently good" decisions [4].

Decision Analysis provides a philosophy of decision, a framework for analysing decision problems, and specific tools and approaches to manage the various forms of complexity decision makers must face [2].

The essence of the DA philosophy is that uncertainty is everywhere because our knowledge of the world is incomplete. It causes bad outcomes to follow from careful and sound decisions, and good outcomes to follow even ill-considered and foolish decisions. The best that you can do is to seek sufficient understanding of what can affect decision outcomes in order to make a good decision according to the purpose and importance of the decision [2].

Howard (2000) [5], who coined the name "Decision Analysis," introduces to executives and students, alike, the DA framework giving the six elements of any decision using the figure of a committed decision maker sitting on a three legged stool [5]. The three legs of the stool (see Figure BA5-1) are:

1) "What you want" (decision maker and stakeholder preferences);
2) "What you can do" (the available menu of alternative decisions); and
3) "What you know" (information relevant to the outcomes to be expected from each alternative).

The seat of the stool represents:

4) The logic used to apply information and preferences to the evaluation of alternatives in order to identify the best course of action.

The stool, which can be placed anywhere, sits on a specific piece of floor called:

5) The decision frame (the defining elements of the decision requirement, including its purpose, its constraints, what classes of alternatives will be considered, and whose decision it is to make).

[12] For more on what is meant by "good decision making," see Appendix 6, of Annex B.

The committed decision maker represents the readiness to make and fully implement the best of the alternatives, which depends upon all of the above as well as the quality of process used to prepare the decision, particularly when there are multiple stakeholders [6].

Systematic treatment of these elements enables selection of worthwhile analysis and realistic alternatives that:

- Make the most of the information and control available to the decision maker;
- Offer the best prospect for a good outcome with acceptable risk of bad results;
- Can be clearly communicated to any part of an organization or its shareholders; and
- Will be executed effectively according to plan.

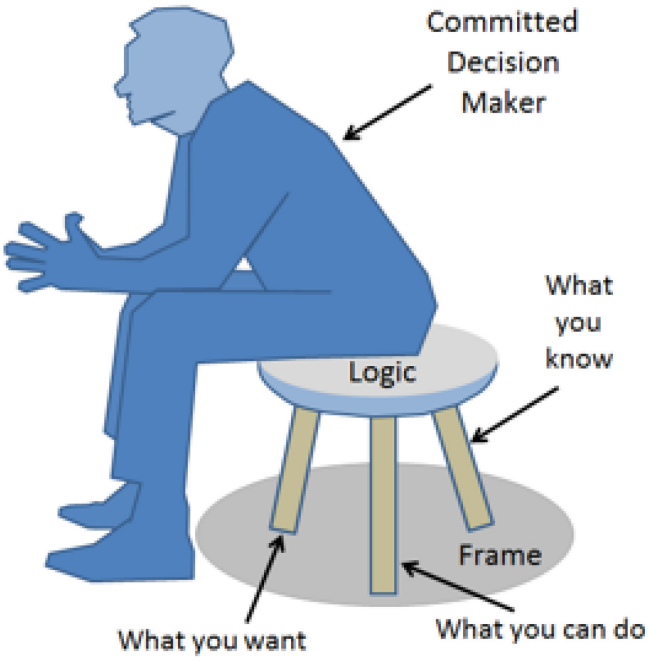


**Figure BA5-1: The Elements of Every Decision [7].**

Key tools used in decision analysis, among others [2] are:

a) **Multi-Attribute Value and Utility Theories (MAVT and MAUT) –** implementations of rational choice theory assuming perfect and imperfect knowledge, respectively, that enable the development of measurable value functions by exploring decision-maker preferences [8]. Other less-powerful approaches sometimes used include Outranking methods and Analytic Hierarchy Process [9].

b) **Influence Diagrams –** Formal structures for identifying causal and sequential relationships between possible decision components, uncertain environmental factors, and outcomes. Influence diagrams map out the factors to be navigated that are within and outside the control of the decision-maker [2], [10].

c) **Decision Trees –** Formal structures for exploring the merit of component decisions in light of probable resulting environmental states and payoffs. Decision trees enable systematic evaluation of the cumulative effects of influence diagrammed factors on outcomes by assigning discrete representative probabilities, costs, and payoffs to possible resulting states. They also enable measurement of the value of new information and improved control of future states [2], [10].

d) **Tornado diagrams –** Graphical representations of the sensitivity of desired outcomes to decision and environmental factors. The usefully direct attention to the most and away from the least influential factors on quantitative outcomes [10].

e) **Decision Process –** Systematic approaches to ensure the decision maker and stakeholders provide guidance and information for analysis and come to a clear, defensible, and risk-informed course of action they are fully prepared to execute [9], [10], [11], [12].

f) **Value-Focused Thinking –** A suite of techniques for decision framing (identifying the boundaries around the decision: what will be assumed, what will be decided later, how the decision should be made and by whom, the fundamental objectives and the measurable sub-objectives) and for developing a menu of creative, feasible alternatives [13].

g) **Non-Compensatory Methods –** When trade-offs between multiple decision objectives cannot be identified (non-dominated sorting, satisficing, sequential elimination, and Maximin/Minimax approaches). Tate and Thompson [9] recommend an overview of these methods by Yoon and Wang [14].

h) **Improved interaction and elicitation techniques –** For obtaining expert information and judgments with minimum bias [2].

The Decision Analysis Society is a part of the Institute for Operations Research and Management Science (INFORMS) and publishes a peer-reviewed international journal, called Decision Analysis, devoted to the field.

A comprehensive treatment of multi-attribute utility analysis is provided by Ralph L. Keeney and Howard Raifa [8]. Keeney has published many key pieces of the literature including *Value-Focused Thinking: A Path to Creative Decisionmaking* [13] and "Structuring Objectives for Problems of Public Interest" [15].

More details on structuring a decision problem are provided in Buede's Structuring Value Attributes [16]. More details on weighting are provided in Borcherding et al.'s Comparison of Weighting Judgements in Multiattribute Utility Measurement [17] and Léon's On the Death of SMART and the Birth of GRAPA [18]. An easy textbook with step by step instructions for applying this methodology is Kirkwood's *Strategic Decision Making: Multi-objective decision analysis with spreadsheets* [19]. Another popular reference is Gregory et al. 2012 [20].

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# Appendix B.6: DECISION QUALITY

The best decision alternative is the one that best serves the achievement of desired outcomes. However, many things can interfere with the efficient discovery, recognition, and implementation of high quality alternatives. The Decision Analysis (DA) discipline offers a construct called Decision Quality (DQ) designed to highlight decision dimensions that mitigate the factors that undermine selection of the best courses of action.

The quality of a decision is established at the time the decision is made, and is based on how it was made, not necessarily on the outcome. Decision quality refers to how well available information at the time was applied to the development and evaluation of feasible alternatives toward achieving desired outcomes. How things unfold afterward depends not only on the decision, but also on how any assumptions and other variables taken into account in the decision actually materialize. Actual outcomes do not change the quality of the original decision at the time it was made, although realized outcomes can be the occasion for analysis lessons learned. Since a DM should not be held responsible for what cannot be known and what is beyond her control, such exogenous factors do not impact assessment of the quality of the original decision.

The DQ construct presents a taxonomy of six dimensions present in every decision. It was developed from cumulative experiences within the DA profession counteracting each of the different ways a Decision Maker (DM) can make a foreseeably bad decision and/or waste time and effort in making a good one. By understanding the meaning of each dimension and what excellence means in each of them, decision makers come to understand both what they have been previously settling for when they decide and begin to deliberately choose the standards for each dimension that are more appropriate to the problem being addressed. The match of decision quality in each dimension to what the situation calls for is the definition of a high quality decision. Knowing how to evaluate each dimension enables conscious explicit recognition of when a decision is ready to be taken.

The six dimensions of decision quality match the decision elements introduced in Appendix B.5 as follows:

1) The decision **Frame** (the problem to be solved; decision objectives, scope, and boundaries);
2) Creative, feasible **Alternatives** (including the strong, the innovative, and the best hybrid options);
3) Clear **Values and trade-offs** (reflecting value preferences and priorities);
4) Relevant and reliable **Information** (with its limitations, assumptions, and uncertainties);
5) **Sound Reasoning** (using the information to judge alternative value, cost, and risk); and
6) **Commitment** to a decision (including supported plans that manage the choice's main risks).

Much like the strength of a six-link chain, the quality of a decision is no greater than the quality of its weakest link or DQ dimension. Poor quality in any of these undermines the quality of the decision taken. A high quality decision occurs only when the quality of all six DQ dimension reach 100%. The standard 100% standard is the point of diminishing/net-negative returns, when the added benefit expected from further work to improve a decision dimension does not justify the cost in time and/or resources. A score of 0% reflects the worst of commonly seen decision-making behaviours. Rating the quality of each DQ dimension is necessarily subjective, but can be aided by shared observations, consideration of the attributes of each DQ dimension and thoughtful application to the decision at hand.[13]

[13] The dependency of DQ on the performance on each DQ dimension implies use of the MIN function to aggregate DQ dimension scores into an overall DQ, although use of the harmonic mean to aggregate scores is a less severe alternative sometimes used [1].

Although the DQ construct is not a procedure or decision process, it necessarily implies some sequential logic. DQ is best interpreted as a set of six lenses that bring into the DM's field-of-view every type of decision hazard so that they can be adequately avoided as the DM selects a course of action. As an illustration, the sixth dimension, *commitment to follow through on a decision*, depends strongly on whether or not the decision process included all the necessary stakeholders, something that needs to be recognized when the decision is being framed. The significant dependencies between the DQ dimensions are highlighted at the end of this appendix.

The power of DQ as a tool is that it sets up consistent judgements regarding where and how much more attention is needed before making a decision. The framework enables an efficient and coherent assessment of every necessary aspect in any decision where the difficulty and stakes require more careful consideration, whether deciding informally or in a pre-defined process, linear or iterative. This feature makes the DQ framework completely scalable to decisions at any level of consequence or complexity. Whether as a series of rapid mental checkboxes for decisions of novelty or moderate impact or a formally elicited set of judgements regarding resolution of crisis, the DM must ultimately evaluate what is good enough in each dimension.

The following sections explain each dimension of DQ, including decision pitfalls each dimension helps you avoid, and general principles of how quality in each is achieved and evaluated. They are documented here principally from Spetzler et al. [2] and Chapters 2 and 3 of Matheson and Matheson [1]. Sample descriptions to anchor ratings are offered for 0%, 50% and 100% for each dimension, though the 50% description is the most notional as there are more ways to achieve a mixed quality than there are to end up at either extreme. The problems to be avoided by each DQ dimension and score anchors are adapted principally from Chapter 9 of McNamee and Celona [3].

Setting a 100% standard for each DQ dimension is the decision maker's responsibility, according to her assessment of the outcomes at stake. Somewhat elaborate procedures are offered here within a DA context that assume the decision is complex, high-impact, and worthy of the most careful consideration, that the need for the decision is foreseen and that adequate time is available for the decision process to explore thoroughly the option space to reach a decision with strong potential to address the need, and that the decision maker deems the effort warranted. Less elaborate or differently aimed analysis will be appropriate according to the DM's assessment of the decision context.

## BA6.1 An Appropriate Decision Frame

The decision frame defines the problem to be solved and the boundaries of its solution: decision intent, scope, available resources, and constraints. In general, there are many ways to view a complex problem, each leading to a somewhat different frame. An appropriate frame ensures that the decision targets the right issues, makes clear the perspective from which decision alternatives will be developed and evaluated and identifies the desired benefits. It also conforms to requirements stipulated at higher authority levels, reflecting, and complying with choices of strategy already made. Community membership imports a larger context into the decision frame. The outcomes to be pursued by the decision can have an impact on not only the future of the community and one's place in it, but also on the resources that may be available within the community to address desired outcomes that community members share, which makes them interested stakeholders. Conversely, the frame should also acknowledge those parties aligned against the intended outcomes and the potential for competition to undermine the success of decision implementation achieving its intent. The decision scope distinguishes the classes of decision alternatives that will and will not be considered and should refer to relevant policy-based and ethical constraints, as well as resource limitations. Since some constraints, risks or undesirable outcomes may be known only to those directly affected by the

decision or to others responsible for implementing the decision, it is important to access the perspectives and insights of stakeholders in formulating the decision frame.[14]

The frame can be the most challenging DQ dimension since it defines the problem-solving field-of-view, the box within which decision making will happen. It frequently occurs that those involved in the decision process think the frame is obvious, even while each conceives it differently. Early frame clarification pre-empts many problems when they are easiest to deal with and highlights dynamics to be managed carefully while there is still time to shape the decision process. Giving decision participants the opportunity to separately define the problem to be solved before sharing with the group provides a starting point for clarification toward agreement on the decision problem [4].

The scope of the decision is the set of component sub-decisions necessary to achieve the full intent for the current decision, including the defining limits on the menu of alternatives to be considered. When the scope of the decision is clear, those participating in the decision process understand what is called the decision hierarchy [3], a categorization of every component sub-decision relevant to the context as either:

1) Decisions already taken, governing, or informing the present decision and not to be revisited (out of scope, in the past);
2) Decisions to be made through the current decision (in scope); and
3) Decisions that will be decided later (out of scope, in the future).

Decision intent is most usefully defined in terms of decision objectives that state the desired outcomes to be achieved by the decision. Complex decisions typically pursue multiple conflicting objectives. Putting these objectives into words clarifies the decision context. They typically evolve as the decision is better understood and attempts are made to measure how well alternatives achieve them. Objectives that are SMART (Specific, Measurable, Achievable by the execution of the current decision, Relevant to the fulfilment of higher level mandates and Time-bound) enhance clarity of thinking.

The evaluation of decision alternatives can be further improved if stated objectives are not just SMART but also *fundamental*:

- At the most strategic level the decision scope allows (limited by what is Achievable);
- Operational: practical for use and readily understandable;
- Mutually exclusive, so they are not causally linked by either whole-part hierarchical relationships or means-ends relationships (so that measurement of their achievement does not give rise to double counting);
- Collectively exhaustive, so they comprise a complete set spanning the full range of issues the decision must address; and
- Minimal, no more in number than necessary.

The selection of a set of fundamental objectives is the result of exploring how the decision, external factors and intermediate outcomes interact to affect achievement of desired outcomes, which may include the avoidance of those not desired. This means articulating a variety of desired outcomes, acknowledging how they interrelate, including recognizing means-end relationships as well as whole-part relationships between higher level objectives and lower level component sub-objectives. The development of fundamental objectives that break down into measurable component sub-objectives sets up tractable terms on which to evaluate decision alternatives. Keeney [4] offers useful guidance on how to develop and harness the power of fundamental objectives.

[14] This will be critical in achieving commitment to decide, the sixth DQ dimension.

The quality of a decision can be no better than the quality of the frame. The frame sets the decision's aim, defines conditions for success, and provides a field-of-view in the search for decision alternatives from which to select the best course of action.

### BA6.1.1 Pitfalls Avoided with an Appropriate Decision Frame

Attempting to make a complex decision without clearly stating the key elements of the frame leaves an unmapped minefield of conflicting assumptions, expectations and cross-purposes waiting to frustrate constructive communication with stakeholders. The search for solutions will be arbitrarily narrow and inconsistent, hampered by serious blind-spots that miss opportunities or, unrealistically broad including some alternatives with unrecognized infeasibilities, unlikely to achieve desired aims. Fully articulating the decision frame will clarify shared intent and assumptions, facilitate the search for alternatives and the development of decision criteria, and avoid misunderstandings later in the decision process. The frame for complex, non-routine decisions will typically evolve as the decision process confronts creative or infeasible alternatives, the complexity of estimating how well an alternative will satisfy fundamental objectives, information gaps and the results of supporting analyses [2].

### BA6.1.2 Topics Relevant to Decision Frame Quality

Considering and discussing the following questions will help develop a sense of how well the decision is framed:

- What does the decision need to accomplish?
- What issues outside the frame are most closely related to, or might impose constraints on issues inside the frame?
- Is it clear what has already been decided and what should be decided later?
- Have we defined all the classes of decision alternatives able to achieve decision intent?
- Are the decision objectives truly fundamental or means to higher decision ends? Can the decision achieve more?
- Can the decision achieve all our objectives or are they too broad for this decision? What are the limits of what this decision can achieve?
- How much has the decision frame evolved since the start of the decision process?
- If one of the decisions already taken as given was not already settled, how would that change the frame for this decision?

### BA6.1.3 Rating the Decision Frame

Use the following as anchors for ratings of the quality of the decision frame, interpolating between them as seems appropriate.

- **0% "Frame Blindness" or "Plunging in":** decision scope or assumptions not stated; no identification of decision intent, decision maker(s) not identified.
- **50% "Incomplete or immature frame":** decision maker(s) identified, issues raised but objectives incomplete / unstructured, possible range of alternatives not discussed, little reference to what the decision will and will not include.
- **100% "Conscious, shared perspective":** Clear statement of purpose, scope, decision maker(s), constraints, and common perspective. Agreement on the decision frame.

## BA6.2 Creative Alternatives

Decision alternatives are possible courses of action that carry the potential to solve the problems and/or exploit the opportunities motivating the decision. Their purpose is to present the most promising courses of action to achieve future success. They constitute the menu from which the selection of a course of action will be made. When decisions are narrowly framed, the range of alternatives is also narrow. Weak alternatives also result when a decision is not framed at all and fear of stepping beyond unnamed boundaries demotivates the search.

While competitive private sector entities incentivize the generation of creative decision alternatives, large public sector organizations with stable cultures and no apparent existential threats often fail to fully explore the realm of the possible. In this setting, leadership effort is needed for decision participants to escape narrow and familiar thought patterns, think "outside the box", overcome socially enforced mindsets, discover creative alternatives that unlock value waiting to be realized, and invigorate staff efforts toward better available outcomes.

A good set of alternatives is typically the result of an *expansion stage* in which ideas for how to address the motivating issues and needs are generated, developed, and explored. This is followed by a *contraction stage* in which expertise is applied to cull the weakest ideas until only the strongest alternatives remain. See Chapters 7 and 8 of Keeney [4], Osborn's Brainstorming technique [5] and subsequent refinements (e.g., Nominal Group Technique), and the NATO Alternative Analysis Handbook [6] for more approaches to generating creative alternatives.

Ideally, the set of decision alternatives to be evaluated will be:

- Well defined, enabling clear judgements of their actual merits;
- Significantly different from each other, to efficiently span the full range of possible actions;
- Realistic to implement, so that time spent evaluating them is not wasted;
- Compelling, generating sufficient probability of desired outcomes to justify and stimulate thoughtful evaluation and follow-through planning; and
- Manageable in number, so that pairwise comparison between alternatives is not prohibitively onerous.

### BA6.2.1 Pitfalls Avoided by Creative Alternatives

When there are too few alternatives considered, or if they are predictable or engineered to favour only one option, a mediocre decision is likely, leaving strong alternatives undiscovered and missing the opportunity to achieve superior future outcomes. Poor or limited sets of alternatives constrain those who must evaluate them and implement the one selected. They can result in a decision that delivers worse outcomes than could otherwise be achieved, while wasting effort. A decision can be no better than the best alternative identified.

### BA6.2.2 Topics Relevant to the Quality of the set of Alternatives

Considering and discussing the following questions will help develop a sense of the quality of the set of decision alternatives [2]:

- Are all the alternatives significantly different or minor variations on a single approach?
- Who outside of those making the decision has contributed to the alternatives?
- Do any of the alternatives extend beyond our comfort zone?
- Does the alternative set explore all the best ways we might achieve the decision intent?

- Have we considered expertly imagined options from "outside the box"? What is the wildest idea that has been considered?
- Is each alternative complete and feasible, including all the elements necessary to execute it if chosen?
- Is each alternative internally coherent, with elements that make sense as a set?
- Do the alternatives include those favoured by each of our key stakeholders?
- Are all the alternatives good enough to justify the work needed to evaluate them?
- Is the current strategy ("status quo" or "momentum" alternative), the default alternative before this process, included among the alternatives?
- Have hybrid alternatives been explored that incorporate the best features of the strongest alternatives?
- Is the number of alternatives manageable for the purposes of evaluation and comparison?
- How confident are we the best available alternative is among those being considered?

#### BA6.2.3 Rating the Quality of the Decision Alternatives

Use the following as anchors for ratings of the quality of the decision alternatives and interpolate between them as necessary:

- **0% "Business as usual":** a few conventional alternatives; or one realistic alternative bracketed by two under-defined others; or only the alternatives initially favoured by dominant stakeholders.
- **50% "Creative alternatives":** significantly different, spanning the option space, feasibility not fully verified, no clear winner without careful evaluation.
- **100% "Better alternatives":** refined, feasible alternatives spanning the option space and combining the best features of the original set, leveraging insights from analysis.

### BA6.3 Clear Values and Trade-Offs (Preferences and Priorities)

Decisions are impossible without referring to preferences; facts alone are essential but insufficient. The set of alternatives seldom includes one that performs better in achieving every objective identified in the Frame; if it does, the choice is easy. Therefore, developing values and trade-offs for complex decisions may require specific support from experts in the phenomena that will unfold after the decision is taken. These can help links alternative decisions to the range of expected outcomes of interest to decision owners. Those responsible for making a decision that best satisfies the decision frame use the insights they get from expert-supported analysis in consultation with stakeholders to make judgements concerning the most desired future states and acceptable levels of risk in their attainment. This section addresses decision maker preferences, but these rely upon metrics populated with information, which is the topic of Section BA6.4.

#### BA6.3.1 Multicriteria Analysis

Identifying the best decision alternative to satisfy multiple conflicting objectives constitutes a problem in Multicriteria Analysis (MCA), whose general structure may be represented by a matrix (Table BA6-1) in which each row presents one decision alternative with its respective levels of performance and each column presents one decision objective with the levels of performance achieved by each alternative in its satisfaction, as shown in Table BA6-1. Every type of human endeavour gives rise to problems of this type, and the variety of approaches developed to address them is very broad. We outline the principle relevant approaches below.

**Table BA6-1: MCA Analysis Structure, Sometimes Called a Performance Matrix.**

| | Objective 1 | Objective 2 | ⋯ | Objective $m$ |
|---|---|---|---|---|
| Alternative 1 | $S_{1,1}$ | $S_{1,2}$ | ⋯ | $S_{1,m}$ |
| Alternative 2 | $S_{2,1}$ | $S_{2,2}$ | ⋯ | $S_{2,m}$ |
| ⋮ | ⋮ | ⋮ | ⋱ | ⋮ |
| Alternative $n$ | $S_{n,1}$ | $S_{n,2}$ | ⋯ | $S_{n,m}$ |

The term Multi-Criteria Decision Analysis (MCDA), sometimes called Multi-Criteria Decision Making (MCDM) is commonly used within the global Operational Research community but, despite the "… Decision Analysis" ending, much less so within the DA community which prefers the more carefully defined Multi-Objective Decisions Analysis (MODA). While the oldest and most influential MCDA techniques originated within DA, the OR community has welcomed under the MCDA umbrella a broad variety of innovations that do not adhere to the rational choice foundations of DA, so that usage of the term MCDA now much more closely matches the meaning of MCA [6], [7].[15]

### BA6.3.2 Assessing Benefits

There are two dominant approaches to modelling alternative overall value for service of multiple conflicting objectives. The one recommended here involves developing metrics that indicate service of corresponding decision objectives. The usefulness of metrics is in their power to discriminate between levels of specific types of alternative merit in objective terms. Metrics can then anchor the development of value functions that reflect levels of preference for different metric values, which in turn enable discussions of the relative desirability of compensating forms of value.

A very popular alternative approach that does not define metrics but has many enthusiastic adherents and a long list of satisfied users is the Analytic Hierarchy Process (AHP) of Thomas Saaty [10]. It involves making pairwise comparisons between the relative importance of objectives and sub-objectives on a given level and between the extent to which different alternative decisions satisfy particular objectives, without ever defining metrics, value functions or value trade-offs. For example, AHP populates a set of square matrices with ratios reflecting pairwise comparison judgements and uses eigenvalue decomposition to produce weights for compared objectives and scores for compared alternatives. This is often found to be less difficult for decision makers because it does not confront any of the ambiguity or undiscovered inconsistency in the decision maker's or stakeholders' own mental models. For that same reason, AHP does little to foster the clarification of the meaning of decision objectives or to drive the learning process necessary for the achievement of genuine insight toward a nuanced evaluation of alternatives that will achieve superior outcomes. The actual meaning of AHP results is uncertain because of the many arbitrary elements in its procedure and the ability of irrelevant alternatives by their presence or absence to affect the performance of relevant alternatives, a phenomenon that undermines claimed links between alternative scores and the desirability of corresponding outcome profiles. For these and other reasons [11], we do not recommend Saaty's AHP.

There are a few different types of metrics. Natural metrics are relatively straightforward (speed, operating cost, capacity, mean time between failures, etc.), made up of basic units of distance, scales of effect, event counts, time, personnel, money, or probabilities, possibly in combination. Without a natural metric, one may need to be constructed that captures the essence of an objective or sub-objective, such as Net Present Value, quality-adjusted life years, etc. Constructed metrics can also define possible well-ordered result states by

[15] The reference [8] is part of a website by Merkhofer (2019) [9] giving a very broad and accessible treatment of topics related to investment portfolio Decision Analysis."

description[16] to clearly imply different levels of objective achievement or failure. When objective achievement cannot be measured directly, it is sometimes necessary to measure achievement indirectly with a proxy measure of something known or believed to be correlated with the degree of achievement of the actual objective, such as measuring the concentration of a specific measurable pollutant to represent the more general health of a natural environment.

### BA6.3.3 Determining Metric Level Preferences

Metrics reflecting different levels of objective satisfaction are a first step toward assessing overall benefit, but they will have different units or no units at all. Metrics need to be converted into value functions that indicate the relative desirability of different metric levels to account for preferences that are not linear with metric score. Metrics may not map to value functions on a one-to-one basis; value may be realized only by combinations of metrics, requiring some expert-informed value modelling with two or more metrics. Value functions map the worst acceptable metric score(s) of any alternative to a value of 0.0 and the greatest useful metric score(s) to a value of 1.0 and model the relative preferences for intermediate metric scores. Intermediate scores are mapped by posing questions such as "At what metric score(s) will half the available value be realized?" Intermediate scores are mapped to corresponding intermediate values reflecting the desirability of metric transitions. This mapping requires that metric score ranges for all alternatives be known or estimable.

To the extent that more of one type of value is meaningfully compensated for less of another type, they can be combined to define higher level value measures. The way different types of value should be combined is affected by how much each type of value varies across the variety of alternatives. Weights to be used in combining components of value into higher level value can be determined by asking questions, such as "How much of a more desired value type would you be willing to trade for a full-scale swing in a less desired type of value?" The answers imply weights enabling compensating values of different types to be aggregated into fewer dimensions of merit. By scaling the weights on a given level of the hierarchy so that they total 1.0, the contributions of their corresponding value types can be aggregated to determine combined value at the next level up, which will also be between 0 and 1.[17]

Decision alternatives that deliver outcomes at different times may require trade-off judgements regarding when it is worth waiting for greater value. Where the phasing or timing of outcomes is preferred but not a hard constraint, these judgements may be expressed as time-dependent penalty functions or as value discount rates.

Once metrics have been converted to value and trade-offs defined for those that compensate, a value aggregation matrix is implied of the form of Table BA6-2 for each higher-level aggregation.[18] The index *j* reflects the possibility of different aggregations of compensating value, for which one or more weights will be 0. The minimum and maximum scores are shown to indicate the metric range represented by the variation in amounts between 0 and 1 of specific types of value. The trade-offs are reflected in the swing weights by which values are aggregated to give overall merit.

[16] The 10 tiers of the Technology Readiness Level scale illustrate this approach.

[17] This assumes value types are independent and can be added without double counting, which is only true if fundamental objectives are truly independent. Specific conditions include additive independence and weak-difference independence [4]. Necessary impacts of one metric on another should be identified and corrected in value calculations. See Keeney and Raifa [12] for detail.

[18] Because not all types of value are compensatory, those that do not trade off with any other type stand alone as single value dimensions. Satisficing can be used to explore acceptable levels of these distinct value types in combination.

**Table BA6-2: Value Aggregation Matrix.**

| | Objective 1 | Objective 2 | ⋯ | Objective $m$ | ***Overall*** |
|---|---|---|---|---|---|
| Weights for aggregation | $w_1^j$ | $w_2^j$ | ⋯ | $w_m^j$ | $\sum_{i=1}^{m} w_i^j = 1$ |
| Alternative 1 | $V_{1,1}$ | $V_{1,2}$ | ⋯ | $V_{1,m}$ | $\sum_{i=1}^{m} w_1^j V_{1,i} = V_1^j$ |
| Alternative 2 | $V_{2,1}$ | $V_{2,2}$ | ⋯ | $V_{2,m}$ | $\sum_{i=1}^{m} w_2^j V_{2,i} = V_2^j$ |
| ⋮ | ⋮ | ⋮ | ⋱ | ⋮ | ⋮ |
| Alternative $n$ | $V_{n,1}$ | $V_{n,2}$ | ⋯ | $V_{n,m}$ | $\boldsymbol{M_n}$ |
| Minimum $V$ | $V_{\min,1}$ | $V_{\min,2}$ | ⋯ | $V_{\min,m}$ | $\sum_{i=1}^{m} w_i^j V_{\min,i} = V_{\min}^j$ |
| Maximum $V$ | $V_{\max,1}$ | $V_{\max,2}$ | ⋯ | $V_{\max,m}$ | $\sum_{i=1}^{m} w_i^j V_{\min,i} = V_{\min}^j$ |

Sometimes, aggregated value relationships are not simply additive, such as when aggregated value only comes from two or more simultaneous types of value.[19] . These non-additive value interactions may be represented with multiplicative value functions. Given the vector of metric scores for an alternative is $\mathbf{x} = (x_1, x_2, \ldots, x_n)$ and each metric $x_i$ has an associated value function $v_i$, the general expression for value aggregated\ v(x) is of the form [12]:

$$1 + Kv(\mathbf{x}) = \prod_{i=1}^{n} [Kw_i v_i(x_i) + 1] \tag{BA6-1}$$

where the $w_i$ are weights in the interval [0,1] and $K$ is a (possibly negative) scaling constant. The interpretation of $w_i$ is the amount of aggregated value from the best possible score in $x_i$ and the worst possible score in every other metric. For $n = 2$, the expression expands to give [12]:

$$v(\mathbf{x}) = v(x_1, x_2) = w_1 v_1(x_1) + w_2 v_2(x_2) + Kw_1 w_2 v_1(x_1) v_2(x_2) \tag{BA6-2}$$

This form can model both synergistic and substitutable interactions between investments. Liesiö [13] provides formal procedures for eliciting $w_i$ and $K$ that are only slightly more involved than for those of the additive form:

$$v(\mathbf{x}) = \sum_{i=1}^{n} w_i v_i(x_i). \tag{BA6-3}$$

### BA6.3.4 Non-Compensatory Methods

When decision makers will not or cannot identify trade-offs between different types of value, there exists a family of non-compensatory methods. The most useful are:

[19] See the footnote in Section 5.3.2, second-last paragraph for a Force Effectiveness example.

- Satisficing, which may also be thought of as screening for "good enough" performance in every dimension for which an acceptability threshold is defined; and
- Dominance, which is the elimination of every alternative strictly inferior in at least one metric and no better in all other metrics.

Other non-compensatory approaches include Sequential Elimination and risk-averse Maximin and Minimax approaches, described in Ref.[14] and detailed in Ref. [15].

### BA6.3.5 Risk

A common feature of difficult decisions is uncertainty, the difficulty of knowing future outcomes from current states and decisions, but also of knowing true values for estimated parameters – past and present. Decision Analysts note that the axioms of rational choice indicate that the correct way to evaluate decision alternatives under uncertainty is through multi-attribute utility analysis, which uses probability-conditioned trade-offs, explicit treatment of outcomes as quantified lotteries between which decision makers express preferences or indifference. However, many decision makers have found the burden of such judgements impractically onerous and often asked for alternative analyses. One accepted compromise has been to address uncertain metric scores with associated risk metrics estimating the probability of the metric ultimately coming short of a minimum (exceeding a maximum) acceptable threshold. This quantifies the uncertain component for special aggregation as attributes (benefits, costs, or schedules) at risk [14]. Uncertainty is also addressed in Section BA6.4 on information.

### BA6.3.6 Pitfalls Avoided with Clear Values and Trade-Offs

Without developing metrics that reflect the merits of alternative choices, the real meaning of objectives remains vague and potentially misunderstood. Topics important to minority stakeholders may be left unaddressed, leading to contentious implementation. Without clear discussion of trade-offs among conflicting objectives, the opportunity to develop shared insight is lost, leaving no structure to manage the decision's complexity. The absence of clear values and trade-offs can leave DMs with less meaningful or more arbitrary ways to understand and compare alternatives. Clear trade-offs between more and less certain benefits can prevent inferior outcomes from decisions that assume too much risk or aim too low for predictability. Otherwise, the decision process is more subject to stakeholder personalities, social dynamics, and in the worst cases, corruption.

### BA6.3.7 Topics Relevant to the Quality of Values and Trade-Offs

Considering and discussing the following questions will help develop a sense of the quality of values and trade-offs:

- Do the decision criteria capture all the dimensions of alternative merit that matter?
- Are the value judgements clear and transparent?
- Do the decision objectives reflect input from those who will be directly affected by the decision?
- Do the decision objectives reflect input from those who must implement the decision?
- Do the decision objectives reflect engagement of knowledgeable stakeholders?
- Is it clear how decision alternatives are to be evaluated against decision objectives?
- Have clear trade-offs to which the decision maker is indifferent been identified between different types of alternative benefit?
- Have the implications of risks on the merit of alternatives been determined and stated?
- Have the implications of result timings and delays on the merit of alternatives been determined and stated?

### BA6.3.8 Rating Values and Trade-Offs

Use the following scale to anchor ratings of values and trade-offs quality, interpolating between them as necessary:

- **0% "It's not clear what we want":** preferences not explicit; stakeholders not identified; "intangibles" ignored.
- **50% "Clear value measures":** stakeholders and criteria identified; fundamental value types distinguished; trade-offs need work.
- **100% "Clear trade-offs":** explicit statement of desired results in terms of decision criteria that address objectives; explicit trade-offs made between conflicting criteria; non-compensating values identified; double counting avoided.

## BA6.4 Relevant and Reliable Information

Human reasoning is limited and prone to a wide variety of biases. (See Appendix B.4 for a list of some of the most common over-simplifying heuristics.) Carefully designed analysis can mitigate these limitations, but the information that populates these analyses limit what the analysis can and should address. If high quality information is to inform the selection of a decision alternative – from the design, population, and interpretation of metrics, valuing and trading off of value types, and the evaluation of alternatives – the limitations of what is and can be known be monitored and reported.

Relevant information connects the alternatives (what we can do) with the future outcomes we care about (what we want, including when). This information includes costs and other resource burdens, timings, and the expected attributes of the future relevant to decision objectives. Reliable (usable) information should be expressed in terms of appropriate measurement, not merely word descriptions. The sources of information, the processes that generated it, the assumptions that were applied in its generation and its associated uncertainty should be known and reported, even if the information is commonly accepted.

The usefulness of information is undermined by mismatches between the assumptions pertaining to the problem to be addressed and those on which information was generated. Information with limited fitness for decision purposes should be presented as such if it is to do more good than harm to problem understanding.

Estimates of uncertainty apply not only to future states of nature which cannot be known with certainty, but also to present or past states about which information is limited. Estimates with explicit uncertainty ranges (confidence or prediction intervals) hide fewer assumptions than point estimates and set up important conversations about factors that cause values at the higher and lower ends of the range, drawing out sources of uncertainty and enhancing understanding of what is being estimated and the reliability of the estimate. A practical way to report uncertain information is to record three values: high, median, and low, with 10%, 50% and 90% chances, respectively, of being higher than the true value [16].

Outcomes related to decision objectives unfold over time through intermediate outcomes and factors that affect them. Some of these factors are influenced by our decision but others are essentially beyond our control. Identifying these relevant factors and intermediate outcomes and known correlations between them and our outcomes of interest can enable us to break the problem of understanding the impact of decision alternatives into manageable parts for analysis and later aggregation. Powerful tools for modelling alternative futures include relevance diagrams (also called influence diagrams), decision trees and decision models.

A relevance diagram is a directed graph showing one-way arrows of sequenced correlation or information passage that do not loop back around. A relevance diagram is an extension of a Bayesian Network incorporating outcomes over time and relationships between them, made to also incorporate decisions to be taken and to conclude with metrics of interest. A completed relevance diagram compactly indicates the

configuration of associated decision trees that model information and factor relevance to outcomes and the decisions that set them in motion. Influence diagrams also support analysis of the value of improved information and improved factor control on desired outcomes.

Figure BA6-1 shows an influence diagram clarifying a decision about quitting a current job to work for a start-up. In Figure BA6-1, the ultimate objective is Quality of Life, shown in the rounded rectangle at right. Uncertain factors that somehow correlate with that objective are shown in ovals. Correlative (possibly causal) relationships are shown as arrows. The decision alternatives stem from the rectangle on the left. The diagram is developed by first considering the ultimate objective and identifying sources of uncertainty in its eventual state. The process is repeated for each of these sources of uncertainty until it reaches back to the decision to be taken.

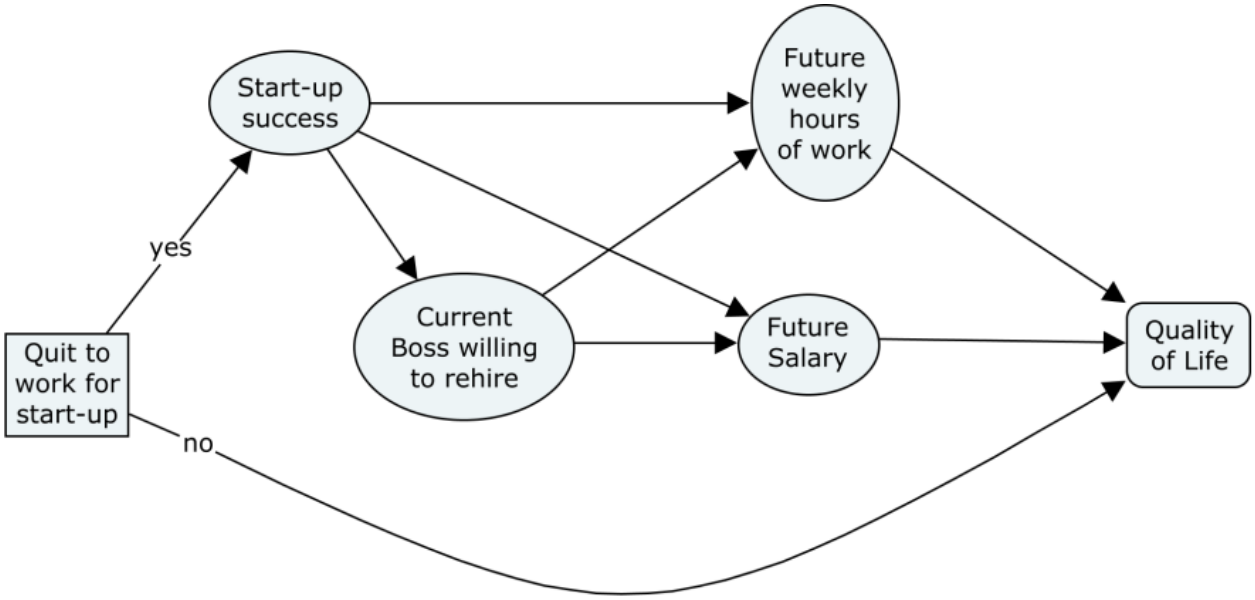


**Figure BA6-1: Relevance Diagram: Quitting to Work for a Start-Up.**

Subject matter experts can sometimes identify intermediate outcomes and factors that influence or indicate the likely outcomes of interest. Expertly facilitated exploration of the mechanisms that link these factors to desired outcomes, conducted to minimize the potential of biased estimation, enables estimation of end-state probabilities, although it must be done expertly to avoid biases before it can be of any net value. Appendix B.4 provides a succinct survey of the most common human biases taken from Chapter 10 of Spetzler et al. [2]. McNamee and Celona [3], and Hubbard [16], also provide a practical protocol for tapping into specialist expertise and eliciting unbiased probability judgements.

A decision tree is a branching structure made up of decision nodes, uncertainty nodes and outcomes. Decision nodes branch into available alternatives leading to other nodes, and uncertainty nodes branch into explicitly possible resulting states of nature with their probabilities and value implications. Decision trees set up calculations of expected value. Figure BA6-2 shows a decision tree corresponding to the Relevance Diagram of Figure BA6-1. Other decision tree variants are also possible. See McNamee and Celona [3] for a thorough treatment of Influence Diagrams and Decision Trees. On information estimation and measurement, Hubbard (2014) [16] is an engaging and enlightening read.

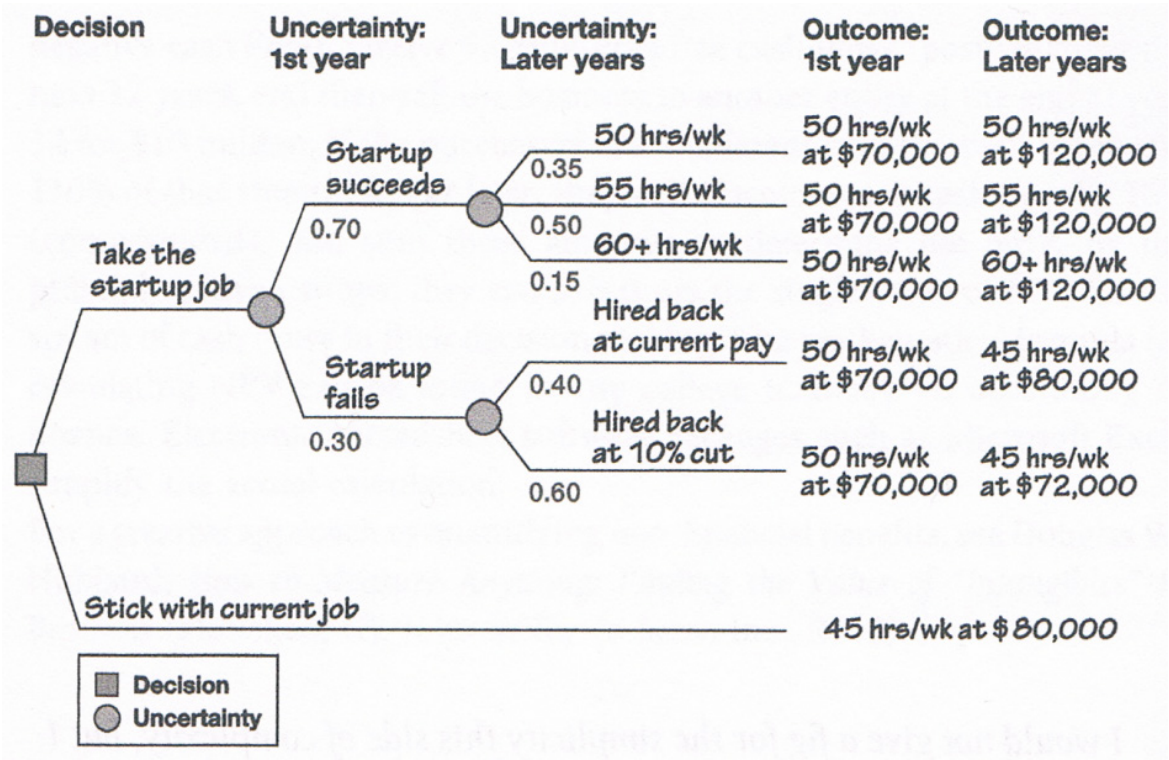


**Figure BA6-2: Decision Tree: Quitting Your Job to Work for a Start-Up from Ref. [2].**

A decision model is a software supported decision tree generally too complex to display all at once but permitting efficient management and calculation of conditional and overall expected value ranges. Useful decision model outputs include Tornado diagrams and Flying bar charts. Tornado diagrams[20] depict as a horizontal bar the expected sensitivity of outcome variables for a given decision alternative in response to the anticipated variation in each input parameter while holding all other inputs constant at their median values. It begins at the top with the widest bar (the most influential input parameter), giving the diagram a tornado-like appearance, emphasizing the most important input variables to understand and influence. A Flying Bar chart shows, as a horizontal bar for each decision alternative, one above the other, the 10% to 90% range of variation in an outcome parameter expected from the combined input parameter probability distributions. It illustrates the nature and degree of uncertainty associated with each alternative.

The quality of the information going into a decision, as it pertains both to the design of any outcome models (mental or explicit) and the parameters that calibrate them, are the sources of all information risk. The quality of the decision cannot exceed the quality of the information on which it is based.

### B.6A4.1 Pitfalls Avoided with Relevant and Reliable Information

Explicit treatment of information uncertainty can be carried through alternative analysis to quantify risks. Probability-conditioned ranges set up conversations about circumstances that lead to true values being at the higher or lower ends, exposing the principal assumptions otherwise concealed in a point estimate, significantly enhancing understanding of the dynamics the decision must manage. Poor information leaves us, at best, guessing in matters where better information would reveal and, at worst, deceived about what alternatives actually promise. It leaves the DM more vulnerable to the types of bias that commonly emerge

[20] Note that sources in the UK offer a different definition of a Tornado Diagram [17]. See the footnote in Section B.6.5, second paragraph.

when good data is not readily available and distortion from competing personal and community interests, conscious and unconscious, is not recognized and managed.

### BA6.4.2 Topics Relevant to the Quality of Information

Considering and discussing the following questions will help develop a sense of the quality of the information enabling the decision process:

- Is the structure of the final decision clear, the sequence in which course of action components should be selected?
- Have data items been specified as point estimates or as possible ranges anchored to probabilities?
- Have risks been identified? Is it known which risks are linked and which ones are independent?
- Has available expertise in decision outcomes been leveraged? (Have intermediate factors and outcomes bearing on desired outcomes been identified? Have relationships been identified between decision alternatives, intermediate factors, and value outcomes? Have ranges of possible states of nature with probabilities been defined?)
- Who provided information on the key uncertainties? How expert are they on the topics on which they provided judgements? Are they trustworthy and reliable?
- Have expert judgements been elicited with procedures that minimize bias?
- Do expert sources agree? If so, have any points of disagreement been captured for consideration?
- Do we know which information uncertainty accounts for the greatest part of our outcomes' uncertainty?
- Have we explored available ways to reduce that uncertainty by improving the information?

### BA6.4.3 Rating the Quality of Information

Interpolate between the following anchor points to rate the quality of information supporting the decision.

- **0% "Blissful ignorance":** Not knowing how much is known or what is important. Ignoring uncertainty and so-called "intangibles."
- **50% "Informed about uncertainty":** Knowing information gaps ("known unknowns") and what is important; uncertainty quantified; interdependencies not explored.
- **100% "Knowledgeable and ready":** information accurate, explicit, and based on appropriate facts; important knowledge gaps filled, and limits of knowledge explored; interdependencies understood and taken into account; sources and rationales well documented.

## BA6.5 Sound Reasoning

Identifying the best decision alternative requires identifying the outcomes expected from each alternative, based on their distinctive features and the best available information, and then selecting the one with highest likelihood of achieving outcomes that satisfy most desired goals and objectives[21]. Sound reasoning requires the use of information identifying and characterizing intermediate outcomes and their relevance to decision objective outcomes, including the influence of dependencies between outcomes. Then, values and trade-offs can facilitate determinations of which alternative promises the most of what is wanted within available time and resources.

[21] When higher authorities are not participating in the decision process, decision results will need to be presented with the range of alternatives considered, including the next strongest alternatives and their characterizations.

Decision modelling software can make it easier to handle the exponential growth in the size of decision trees associated with complex decision problems. Once a decision is modelled, tornado diagrams[22] show how much variation in the outcomes of interest is associated with the expected variation of each intermediate factor or indicator while other factors are held at their median values. Flying bar diagrams then show the most likely value and spread of outcomes along a scale of interest as a result of all identified uncertainties [2].

The modelling of outcome likelihoods should begin with the most influential or relevant inputs to the outcomes of interest and proceed iteratively according to the next most relevant intermediate outcomes. In this way, time and effort are not wasted on factors of little consequence and work is more efficiently channelled to focus on remaining uncertainties.

### BA6.5.1 Pitfalls Avoided with Sound Reasoning

Unsound reasoning may leave the true impact of intermediate outcomes un- or mis-characterized, leading to loss of credibility. Much time can be wasted analysing relatively less important items, leaving more important and relevant (but perhaps more unfamiliar) phenomena not properly studied. The decision may not be supported by a comprehensive evaluation of all alternative outcomes against the objectives, there may be unnecessary reliance on point estimates that conceal risk, or possibly a needlessly complex analysis not conducive to sensitivity analysis or timely decision.

### BA6.5.2 Topics Relevant to the Quality of Reasoning

- Are the outcomes to be expected from each decision alternative characterized clearly in terms of the decision objectives?
- Which factors are most and least influential on the merit of each alternative?
- Does the logic used to develop the outcomes make sense to an intelligent outsider?
- Are assumptions clearly stated?
- Are the tools that support the analysis open to stakeholder scrutiny?
- What drives the principal differences in the merit of the different alternatives?
- Which outcomes face the greatest uncertainty? Which face the least uncertainty?
- Which dimensions of merit are most sensitive to earlier value trade-off judgements?

### BA6.5.3 Rating the Quality of Reasoning

Estimate where the quality of reasoning supporting the decision falls between the following points:

- **0% "Instinctive":** intuitive decision-maker evaluation; risk of self-serving or corrupt motives;
- **50% "Limited visibility":** key sources of value identified; important uncertainties identified; dependencies not accounted for; logic incomplete and/or with insufficient detail;
- **100% "Clear best choice":** reliable analysis of each alternative; uncertainties, dependencies, and complexities accounted for; analysis is "as simple as possible and no simpler"; clear choice based on frame, alternatives, information, and values that reflect fundamental objectives.

[22] We refer here to American tornado diagrams [1], showing sensitivity of outcomes to factors on a horizontal scale with the most influential factors (with the widest bands) at the top and the least influential at the bottom, shaped like a tornado. This differs from the English version presenting a vertical stack of initiatives with cost bars going left and benefits going right [17].

## BA6.6 Commitment to Decide and Act

The sixth DQ dimension becomes especially critical in decision settings with significant organizational complexity, involving a broad range of stakeholders with distinct interests or roles in decision execution whose informed support for the decision can significantly affect its realization. A decision is no better than its implementation or follow-through.

The act of deciding involves a transition from the conflict that drives inferior alternatives out of the picture to collective support for a single, best course of action. It means assuming the risks that cannot be mitigated for the sake of obtaining the best of available benefits. Commitment to decide can be thought of as decision-readiness.

Besides those interested in the outcomes of the decision, high quality commitment to decide and act requires buy-in from those involved in implementing the decision, including those at higher levels who must endorse any decision before it executes. Implementer participation can play a key role in ensuring the decision can and will be followed through. Besides identifying ways to ensure alternatives are developed for feasibility, implementers know where the plan is likely to face challenges and how to ensure implementation preserves the most important parts of the selected alternative, so that the principal merits of the chosen course of action are not traded away in execution for the sake of what are actually secondary considerations.

Commitment to decide is best founded on early "buy-in" and collective confidence built during the decision process that the best alternative to meet the objectives agreed in the decision frame has been identified, that it is sufficiently elaborated to achieve the best available satisfaction of the decision objectives, and that it is time to start implementing. That commitment to decide and act can be undermined by any perceived unaddressed weaknesses in the other five DQ dimensions. For example, including fundamental objectives that only certain stakeholders deem important to build a richer picture. Once corresponding metrics are defined and populated, the preference levels for their corresponding types of value can be clarified with better insight when addressing trade-offs, ensuring that minority stakeholders have been heard and understand the full set of considerations at play in the decision. Conducting a robust evaluation of DQ can reveal when decisions are ready to be made.

### BA6.6.1 Decision Process

A structured decision process can significantly improve the efficiency of reaching a high-quality, long-term decision addressing complex issues. Expert decision-analytic facilitation can do much to orient and execute the decision process to increase decision quality. As a neutral party, facilitators can shift communications away from the dynamics of organizational sub-cultures or alternative advocacy dynamics, and ensure participant input is constructively managed. The learning driven by the decision process leads to refinement of the frame, metrics, trade-offs, and assessments as the implications of constraints, assumptions, available information and judgements are fully developed, new alternatives are discovered. Learning continues as new perspectives emerge that can substantially change how the problem is perceived. The time and decision support resources allocated to the process should foster the learning by which DQ emerges.

Two influential model decision processes or decision process ideals have emerged to support complex decision management while monitoring decision quality. The Dialogue Decision Process involves a sequence of prepared dialogues between a Decision Board with stakeholder representation and an in-house Analysis Team that stakeholder organizations are directed to support, including subject matter experts developing planned products from each process stage. As Analysis Team and Decision Board learning advances, later stages include necessary revisions of earlier products to develop a consistent and complete analysis record. The Dialogue Decision Process is described more fully in Appendix B.7.

The other decision process ideal is called Decision Conferencing and involves a series of decision conference events attended by stakeholder communities with contracted facilitation and proprietary software support, concluding with a final decision conference attended by key stakeholders. Decision Conferencing is further described in Appendix B.8.

### BA6.6.2 Pitfalls Avoided Through Commitment to Decide and Act

Decisions forced through with only DM commitment to decide and without meaningful broad consultation or reflection on process quality lose the last opportunity to recognize and correct deficiencies in framing, alternatives discovery, structuring of preferences, the evaluation of information quality, and of the logic applied to determine the best alternative. They may be headed for the worst of bureaucratic implementation: loss of anticipated benefits that motivated the decision due to unaddressed implementation complexity, slow-rolled execution by unmotivated, under-consulted or ignored stakeholders, or perhaps a full implementation of an inferior alternative because of neglected expertise.

### BA6.6.3 Topics Relevant to the Quality of Commitment to Decide and Act

Considering and discussing the following questions will help develop a collective sense of decision readiness:

- Have we achieved 100% in the other five DQ dimensions? If not, where do we need to focus?
- Are there differences of opinion regarding additional work needed? How shall we resolve these?
- Are we ready to commit to the chosen alternative according to the elements in the decision frame?
- Will all the resources this decision requires be allocated to its execution?
- Are the implementers clear about what is fundamental and what is of secondary importance in this decision?
- Do major risks have mitigation plans? Can they be implemented if necessary?

### BA6.6.4 Rating the Commitment to Decide and Act

Estimate the shared commitment a particular decision between the following anchor points:

- **0% "Unmotivated":** lack of interest of key decision makers; insurmountable organizational hurdles; insufficient support.
- **50% "Active decision board":** active participation by the right people; commitment to achieve decision quality; commitment to "do it right the first time"; buy-in not yet pervasive in the organization.
- **100% "Take action":** buy-in from implementers, decision authorities, and those affected by the decision; sufficient resources allocated to implement and fully execute the decision.

## BA6.7 How DQ Dimensions Interrelate

The principal logical relationships between the dimensions are illustrated in Figure BA6-3.

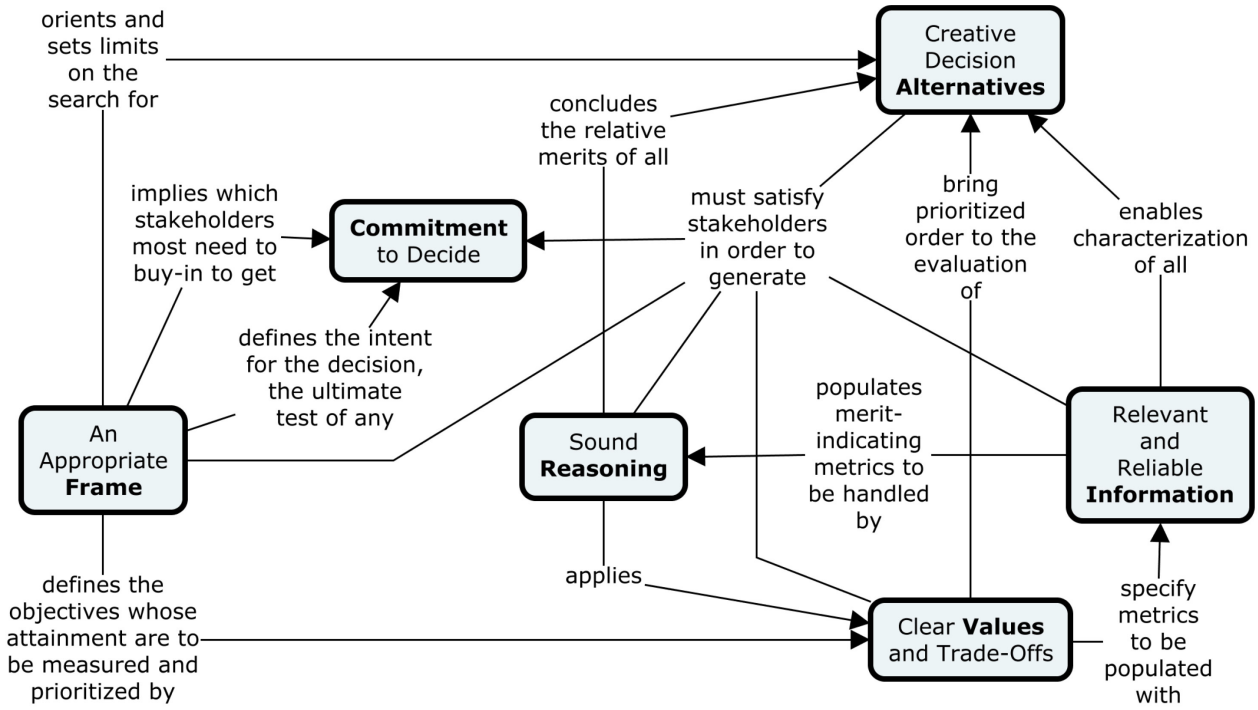


**Figure BA6-3: Dependencies Between Decision Quality Dimensions.**

## BA6.8 The Decision Maker's Bill of Rights

Leaders who must take strategic decisions depend upon their decision support staff for assistance to bring clarity out of complexity. Once they grasp the dimensions of DQ and recognize the value that excellence in every dimension makes available, their expectations rise. The following statement, developed and endorsed by SDG and the Society of Decision Professionals [1], reflects the values such leaders embrace, stated as executive entitlements.

### The Decision Maker's Bill of Rights

Every decision maker has the right to decision quality, achieved through:

1. A decision *frame* that structures the decision in the most relevant context.
2. Creative *alternatives* that enable a selection among viable and distinct choices.
3. Relevant and reliable *information* upon which to base a decision, incorporating the inherent uncertainty.
4. An understanding of potential outcomes of each alternative described in terms of the decision makers' *values*.
5. Sound *reasoning* and analyses that allow decision makers to draw meaningful conclusions and choose the best alternative.
6. An effective decision project leader who can achieve alignment and *commitment* to the best action.

## BA6.9 References


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# Appendix B.7: DIALOGUE DECISION PROCESS

The Dialogue Decision Process (DDP) was developed within the Strategic Decisions Group in Menlo Park, USA. By design, it ensures that senior stakeholders can guide and shape the analysis underpinning the decision when impact and analytical and organizational decision complexity is high, making decision quality difficult to achieve efficiently without a structured process.

The DDP involves a defined sequence of tasks and interactions between two bodies as shown in Figure BA7-1. The decision board makes the decision. It consists of the decision maker and all key stakeholders. The Decision Board directs the formulation of decision elements and ultimately decides after sequential engagement with the Analysis Team. The Analysis Team gathers the information needed (with support from expertise in stakeholder organizations), develops alternatives and assesses the merit of the decision options. The Analysis Team also needs expertise from those implementing the decision and may include their participation [1], [2]. The generic DDP is illustrated in Figure BA7-1.

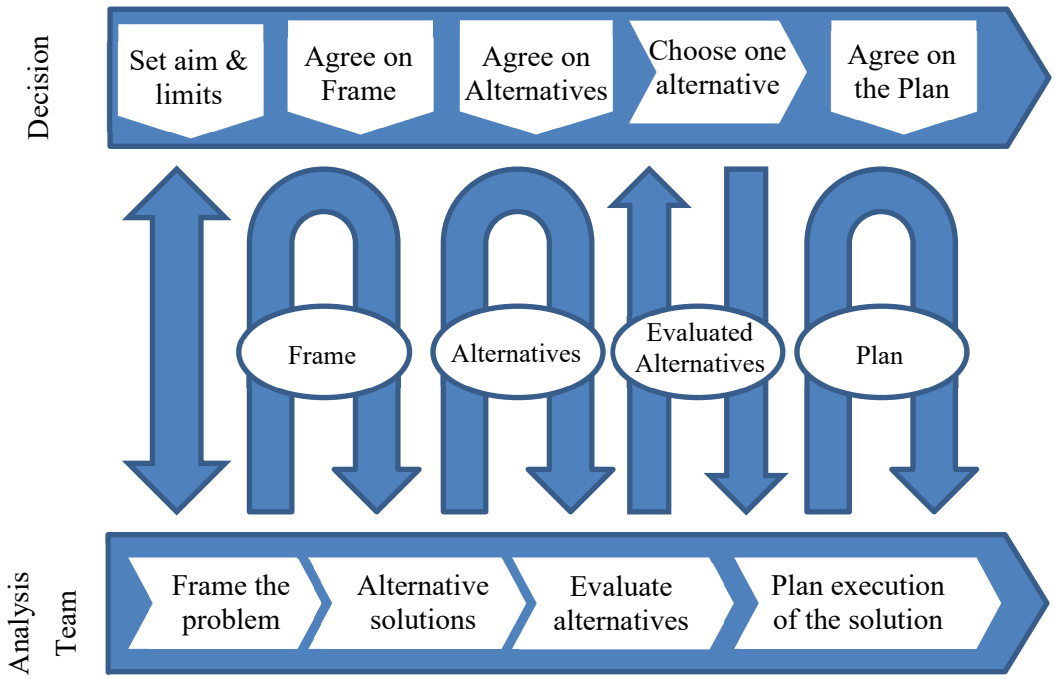


**Figure BA7-1: Dialogue Decision Process After Spetzler (2007) [1].**

In Figure BA7-1:

- The sequence of topics addressed in interactions between the Decision Board and the Analysis Team address the decision frame, the menu of decision alternatives, evaluated alternatives and the plan to execute the decision;
- Each of the six phases of communication is represented by a solid blue vertical (either straight or u-shaped) arrow between the Decision Board and Analysis Team, showing whether it is a consultation or a passage of results;
- Decision Board guidance to the Analysis Team occurs at four points, shown inside the Decision Board bar as white downward-pointing arrows; and
- Five specific pieces of work necessary to advance the decision are shown as solid white arrows pointing to the right, one in the Decision Board bar and four in the Analysis Team bar.

The design of the DDP paradigm includes a member of the decision board having explicit responsibility for evaluation of all six dimensions of decision quality, ensuring that the expertise of senior executives informs the assumptions, priorities, design, and content of the analysis that will guide the decision. It thus mitigates the most pernicious organizational biases: overly-narrow framing, the illusion of decision quality, the agreement trap, analysis confined to the comfort zone, and the advocacy/approval myth, described in Section BA4.3 of Appendix B.4.

The DDP leverages available expertise under senior guidance to generate and refine interim products necessary to reach high quality decisions. As such, the process is generic and can be employed with any decision sufficiently complex to need a structured decision process. A facilitator with decision-analytic expertise can significantly enhance the performance of the DDP in initial usage. As its benefits are experienced, it can become a strong whether engaged under contract or provided in-house.

The literature contains multiple accounts of successful DDP adoption, including General Motors in the 1990s (Ref. [3], pp. 251-255). It has proven particularly valuable in industries considered "decision intensive," where operational efficiencies are broadly standardized and companies compete on the quality of their decisions, with Chevron a case in point [4].

## BA7.1 References

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# Appendix B.8: DECISION CONFERENCING

Decision Conferencing is a decision paradigm in which stakeholders representing the full diversity of perspectives attend a series of focused meetings in order to perform and validate the analysis of decision alternatives. The meetings are professionally facilitated and supported with specialized software to make the development of a (usually additive) value model as efficient and transparent as possible, and to display the state of the analysis throughout its development. This enables collective refinement and exploration of its implications for the decision at hand and can generate broad acceptance of a solution that achieves a suitable balance between a complex set of related challenges [1].

Decision conferencing works best on "hot" issues of broad immediate concern in an organization motivated to find a good resolution. It can be particularly effective in achieving shared understanding, a sense of common purpose and commitment to a way forward. It does this by gradually developing a model of value directly implied by the sensibilities of participants, who are encouraged to share and explore every point on which it seems not to capture reality. Shared exploration of gut-level concerns generates broadly shared perceptions that clarify and distil the problem to its most important features. As understandings deepen, preliminary judgements are revisited and refined until a stable representation of the issues to be addressed is achieved. Afterward, the facilitator prepares a report documenting the meeting, and meets with senior staff to resolve any remaining issues.

The general flow of one DC consulting firm addressing portfolio decisions is shown in Figure BA8-1 after Cree and Bossley [2]. Preparation for the decision conference includes setting objectives with the decision maker, identifying necessary participants, and sending participants invitations with orienting material on the purpose and the process. If the decision maker cannot attend, someone representing her perspectives should participate. In this case, the result of the decision conference will be recommendations to the decision maker.

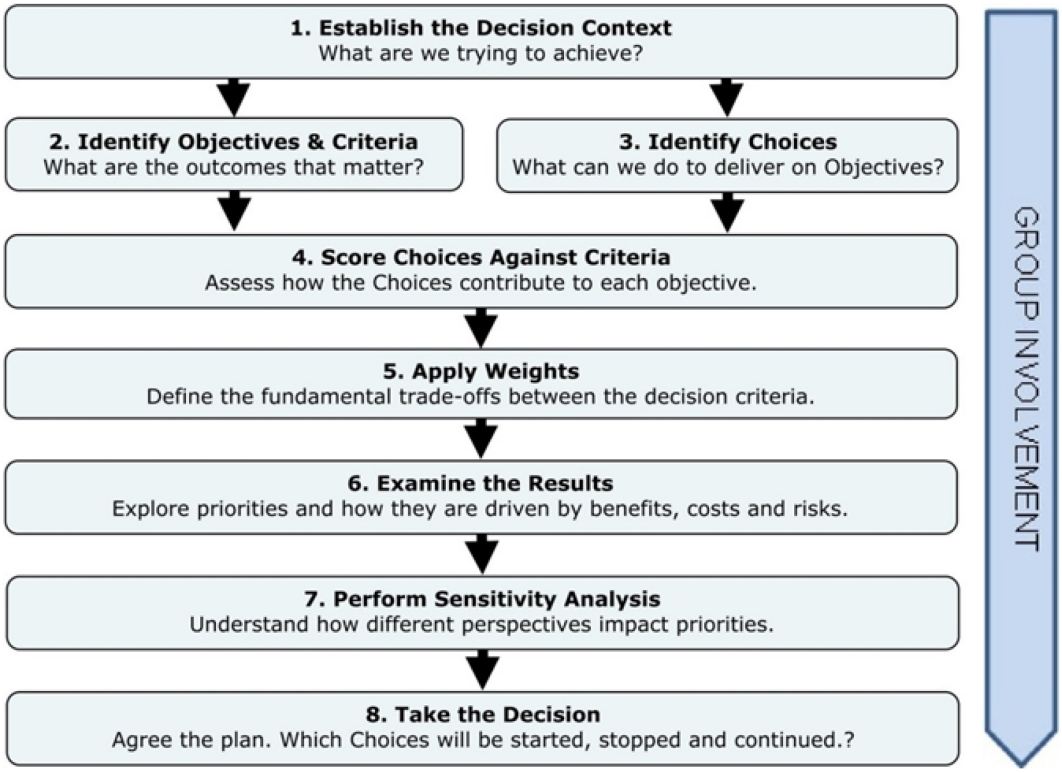


**Figure BA8-1: A Portfolio Decision Conferencing Process. (Source: Cree and Bossley [2]).**

As necessary, preliminary decision conferences can deal with pieces of the larger problem based on somewhat severable problem segments of the problem. This can enable the diverse stake-holding communities across the enterprise to bring specific expertise to bear on judgements within their operational domain. The results are then brought to a final decision conference in which senior stakeholders make judgements that enable the aggregation of results into a full portfolio.

Phillips (2011) [3] documents the very successful use of Decision Conferencing to take the results of an international collaboration on a new frigate aborted due to multi-national partner capability disagreements and transform them over a 15 month period into a destroyer design delivering an optimized, affordable and risk-informed portfolio of destroyer-based capabilities with built-in growth potential.

## BA8.1 References

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# Appendix B.9: DECISION MAKING UNDER DEEP UNCERTAINTY

The principal reason we find decisions difficult is that our knowledge of how they will turn out is limited. However, there are many distinct dimensions of knowledge on which our decisions rely. When uncertainty becomes significant in more than one of them, our confidence in familiar decision support strategies weakens.

The years since 1989 have seen concerted effort to recognize and survey decision dimension uncertainty and to discover sound decision strategies when what we know or can discover is limited in several of them. They are described briefly in this appendix, principally from the introductory chapter [1] of *Decision Making under Deep Uncertainty: From Theory to Practice* (2019) [2] written by its editors, but with emphasis on two particular methods recognized for their potential applicability in defence resource allocation.

## BA9.1 Essentials of DMDU

Deep uncertainty describes a sufficiently large knowledge gap to make good prediction impossible. Such knowledge gaps can pertain to:

1) The probabilities of key variables and parameters (inputs) to the system of interest;
2) How to model the system of interest; and
3) The relative value of desired outcomes from the systems.

Most long-term decisions must confront deep uncertainty; to ignore it with simplistic assumptions is to assume unidentified and unquantified (and therefore unmanageable) risk.

The principal features of a decision problem are represented in the concept map of Figure BA9-1. A system (R), subject to external forces (X) produces outcomes (O). Decision makers have goals, objectives, and preferences (W, for wishes) regarding possible outcomes, as do the stakeholders they affect. Decision makers want to select a policy (P) that influences the system to generate preferred outcomes. Uncertainty can exist in each of the lettered concepts in the diagram. Our knowledge of X, R, and O can vary from limited to total nescience (knowing nothing), depending upon the problem, preventing confident selection of P. The variation in values between decision maker and stakeholders can be very broad, obscuring the means for measuring the strength of alternative policies.

Marchau et al. [1] provide a framework for understanding the four different types and five levels of uncertainty between (but excluding) certainty to the left of Level 1 and nescience in the right-hand side of Level 4, shown in Table BA9-1.

The literature refers to the traditional decision support paradigm as “predict-then-act,” but deep uncertainty prevents confident prediction. Scenario-based planning can effectively manage up to Level 3 uncertainty but is infeasible as the multiplicity of plausible futures exceeds what scenario-based planning can manage. The techniques of DMDU tend to be more costly than “predict-then-act” analysis, but their ability to guide actions through deeper uncertainties makes them worthwhile for certain classes of problems illustrated in Figure BA9-2. (Here, “Uncertainty” reflects the dimensions of X, while “Complexity” reflects disagreement over the probabilities associated with X, how to model R and the resulting variety in O.) DMDU does not help when uncertain dimensions of X are clear and when system complexity is low. It can offer most help when uncertainty is deep in multiple dimensions, but especially so when there are a great many policy options.

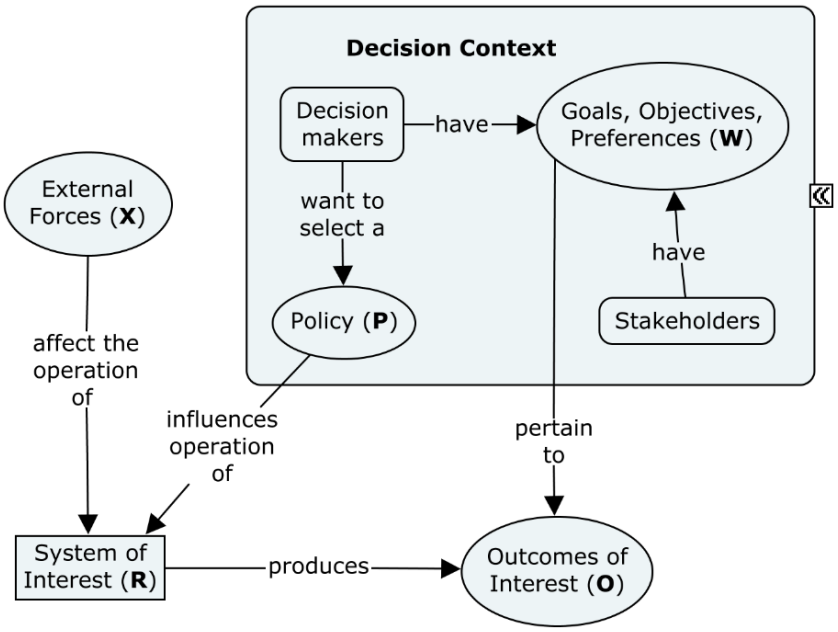
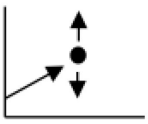
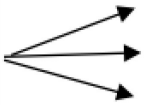
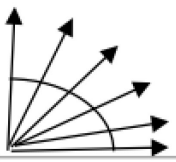
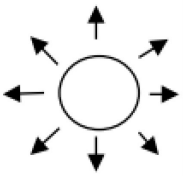



**Figure BA9-1: A Framework for Decision Support.**[23]

**Table BA9-1: Levels and Types of Uncertainty Bounded by Certainty and Nescience.**

| | Level 1 | Level 2 | Level 3 | Level 4 (deep uncertainty) | |
|---|---|---|---|---|---|
| | | | | Level 4a | Level 4b |
| Context (X) | A clear enough future  | Alternate futures (with probabilities)  | A few plausible futures  | Many plausible futures  | Unknown future  |
| System model (R) | A single (deterministic) system model | A single (stochastic) system model | A few alternative system models | Many alternative system models | Unknown system model; know we don't know |
| System outcomes (O) | A point estimate for each outcome | A confidence interval for each outcome | A limited range of outcomes | A wide range of outcomes | Unknown outcomes; know we don't know |
| Weights (W) | A single set of weights | Several sets of weights, with a probability attached to each set | A limited range weights | A wide range of weights | Unknown weights; know we don't know |

[23] This model of XPROW appears in parts of the literature as XLRM: X (exogenous, as above), Levers (of policy), R (relationships, as above) and M (measures, combining Outcomes and Wishes).

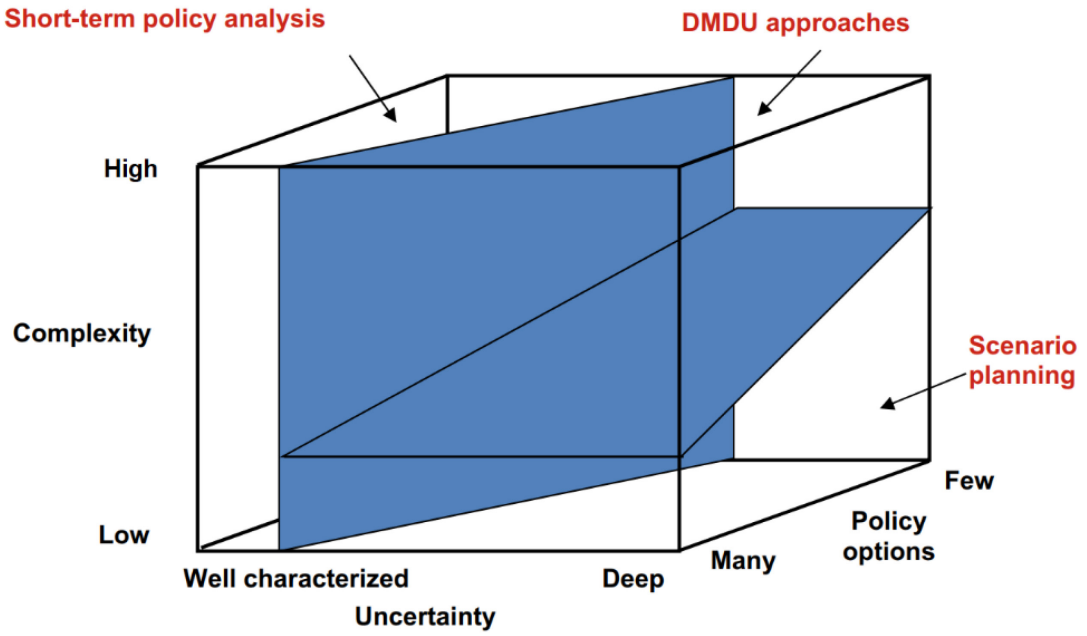



**Figure BA9-2: When DMDU Can Provide Benefits Exceeding its Costs.**

## BA9.2 Two Relevant DMDU Methods

A variety of DMDU methods have been developed, all designed to meet the need for actions to reduce the vulnerability of any policy to uncertain future developments. Two with specific relevance to Defence planning [3] are Assumption-Based Planning and Robust Decision Making, which are summarized here briefly.

### BA9.2.1 Assumption-Based Planning

Assumption-Based Planning (ABP) [4] is the earliest such method, designed to improve the adaptability and robustness of existing plans. It provides "a systematic way of thinking about a future containing fundamental uncertainties about an organization's ends and a framework for, over time, dealing explicitly with those uncertainties." Beginning with an existing resourced plan to achieve ends and a planning time horizon over which uncertainties are to be managed, the steps of ABP (with their flow illustrated in Figure BA9-3) are as follows:

1) Planners develop a list of the most important assumptions on which success relies. Assumptions are important if their future negation is plausible and significantly detrimental to the current plan's success.
2) Planners identify plausible events within the planning horizon that would negate important assumptions (identifying them as vulnerable).
3) Develop signposts, clear indicators that a vulnerable assumption is showing signs of weakening (and plan to monitor them to trigger future-shaping actions).
4) Develop shaping actions, initiatives that can favourably influence the status of vulnerable assumptions.
5) Develop hedging actions that will mitigate the consequences of important assumptions failing (usually by exploring a post-failure world for consequences that preparation can mitigate).

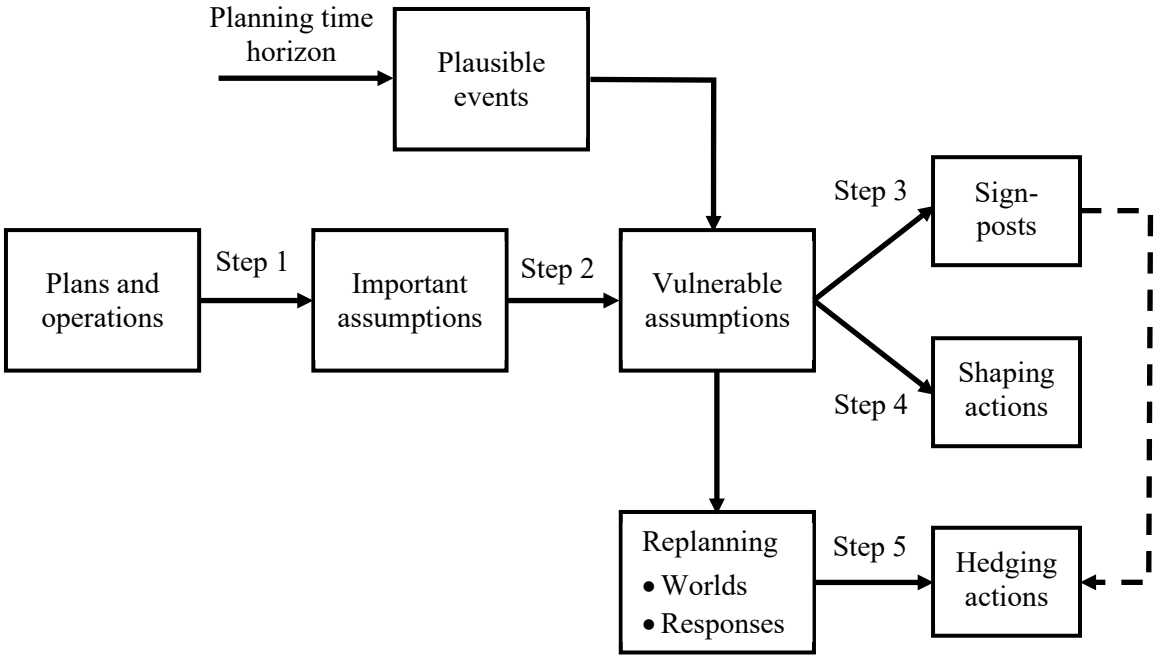



**Figure BA9-3: Assumption-Based Planning from Ref. [4].**

The trade-off between completeness and effort must be consciously managed. The list in Step 1 can be large, but the list of event-negation pairs from Step 2 may exceed what can be run through steps 3 through 5 with available resources and may need prioritizing. Development of alternative worlds embodying failed assumptions greatly helps with design of hedging actions. Shaping actions that will take longer to complete than the notice provided by corresponding signposts should be implemented in the current planning cycle, as should hedging actions that are not too disruptive. Disruptive actions may be delayed if signposts can provide enough advance warning. Steps 3 through 5 can be conducted in any order, though their numbered order embodies a completed transition from "how to think" to "how to act" [4].

### BA9.2.2 Robust Decision Making

Robust Decision Making (RDM) is an iterative, quantitative approach designed to remedy the challenges of predictive failure. It has matured enough to be used recently to guide energy, environment, climate, infrastructure, and insurance industry decisions [5]. It represents "a new synthesis of four key concepts: Decision Analysis, Assumption-Based Planning, Scenarios and Exploratory Modelling." Figure BA9-4 is a common depiction of the steps of RDM.

Instead of seeking optimal utility (probability-weighted value), RDM seeks robustness, the property of performing acceptably well over the largest possible range of plausible future states. RDM uses exploratory modelling to vary assumptions and future-shaping parameters in combination across their plausible ranges to approximate all plausible futures as stress-tests of each alternative. The body of results is then systematically explored to discover mathematically vulnerability scenarios of similar success-relevant outcomes and their principal determinants in the tested policies. These inform discussions of trade-offs between scenario phenomena and can also lead to the development of new hybrid policy options. RDM extends ABP's testing of load-bearing assumptions and follows up with adaptive strategies that identify of the most relevant signposts, shaping actions and hedges to develop decision rules that course-correct as information about the future emerges.

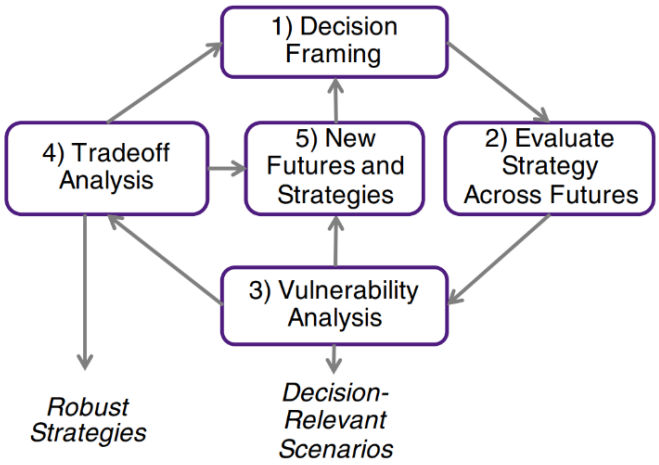



**Figure BA9-4: Robust Decision Making Flow from Ref. [5].**

In 2016, RAND Corporation published a study [5] requested by the Cost Assessment and Program Evaluation (CAPE) Directorate within the Office of the U.S. Secretary of Defense (OSD) that the utility of RDM be evaluated for Defence purposes. The study responds by using RDM to determine the most effective and affordable policy for air-delivered munitions procurement, presenting a much more uncertainty-informed analysis than the scenario-based planning of the contemporary Munitions Requirements Process.

## BA9.3 Generic DMDU Process Model

ABP, RDM as well as Dynamic Adaptive Planning, Dynamic Adaptive Policy Pathways, Info-Gap Decision Theory and Engineering Options Analysis – other DMDU methods addressed in Ref. [6] – can all be understood as variants of a generic DMDU paradigm. This paradigm is described in Ref. [1] and cross-tabulated here with the dimensions of Decision Quality in Table BA9-2.

## BA9.4 DMDU for Defence Investment Prioritization

It must be remembered that long-term defence capital investment constitutes a set of moves in a strategic game, in which each players actions are informed by the others. Methods that manage a future that is principally the result of impersonal or even broad social forces will not be sufficient for determining policy that must counter intelligent adaptive adversaries. There has been military push-back against RDM in some settings because it tends to discount worst-case scenarios as just one of many equally probable outcomes. A portfolio that performs well against most things can miss a few key elements needed to counter threats of specific military concern [7]. Hence, future elements that cannot be known must be carefully distinguished from those that can, such as adversarial movement of the future into domains against which allied performance may be weaker.

## BA9.5 Other DMDU Resources

The Society for Decision Making Under Deep Uncertainty maintains a website with accessible webinars presenting instances of various DMDU techniques [8], including ABP [9] and RDM [10].

**Table BA9-2: Common Stages in DMDU Methods and their Corresponding DQ Dimensions.**

| DMDU DQ → | | Frame | Alternatives | Values and Trade-Offs | Information | Logic | Commitment |
|---|---|---|---|---|---|---|---|
| **Frame the analysis** | Generate problem / opportunity questions | Define the problem | | | | | Identify stakeholders, and analytical approach |
| | Gather info. and specify system structure | Scope the ways | | | Identify causal relationships | | Identify system actors |
| | Generate problem / opportunity questions | Desired ends | | | | | |
| | Discover alternative Courses of Action | Scope the decision options | Identify system lever settings to considered | | | | |
| **Perform exploratory uncertainty analysis** | Generate uncertain futures | | | Specify uncertainties in W | Specify uncertainties in X, R, and O; Derive possible futures | Discover success and failure scenarios, and policy factors | |
| | Test alternatives against futures | | | | | Extend information | |
| **Choose initial and contingent actions** | Examine trade-offs and weigh choices | | | Determine future preferences | | Evaluate alternatives | |
| | Select initial policy and contingencies | | | | Identify policy change need indicators to monitor | | Determine and plan best option and adjustments |
| | Communicate and monitor results | | | | Establish indicator monitors | | Implement plan |

## BA9.6 References

[1] Marchau, V.A.W.J., Walker, W.E., Bloemen, P.J.T.M. and Popper, S.W. (2019). Introduction. In: V.A.W.J. Marchau, W.E. Walker, P.J.T.M. Bloemen, and S.W. Popper (eds.), Decision Making under Deep Uncertainty: From Theory to Practice. Springer Nature Switzerland AG: Gewerbestrasse, CH.

[2] Marchau, V.A.W.J., Walker, W.E., Bloemen, P.J.T.M. and Popper, S.W. (eds.) (2019). Decision Making under Deep Uncertainty: From Theory to Practice. Springer Nature Switzerland AG: Gewerbestrasse, CH.

[3] Leftwich, J.A., Knopman, D., Fischback, J.R., Vermeer, M.J.D., Van Abel, K. and Kalra, N. (2019). Air Force Capability Development Planning: Analytical Methods to Support Investment Decisions. RAND Report RR2931. RAND Corporation: Santa Monica.

[4] Dewar, J.A., Builder, C.H.W., Hix, M., and Levin, M.H. (1993). Assumption-based planning: A planning tool for very uncertain times. RAND Monograph Report MR-114-A, RAND Corporation: Santa Monica.

[5] Lempert, R.J., Warren, D., Henry, R., Button, R.W., Klenk, J. and Giglio, K. (2016). Defense resource planning under uncertainty: An application of robust decision making to munitions mix planning. (RAND Report RR1112.) RAND Corporation: Santa Monica.

[6] Lempert, R.J. (2019). Robust Decision Making (RDM). In: V.A.W.J. Marchau, W.E. Walker, P.J.T.M. Bloemen, and S.W. Popper (eds.), Decision Making under Deep Uncertainty: From Theory to Practice. Springer Nature Switzerland AG: Gewerbestrasse, CH.

[7] Ween, A. SAS-134 20210512 Webex Summary. May 2021.

[8] The Society for Decision Making Under Deep Uncertainty (2020). 2020 DMDU Webinar Series. https://www.deepuncertainty.org/2020/04/14/dmdu-webinar-series/ (Accessed 14 May 2021).

[9] Popper, S.W. (2020). Assumption-Based Planning. 2020 DMDU Webinar Series, The Society for Decision Making Under Deep Uncertainty, 2 June 2020. https://itesm.zoom.us/rec/share/zMl1Ba3X5kZJXLPAzgb_Qp4HRbzMX6a8hyFN_qZb-E9LjeAg9zIecIE4HfRg4A Password: 5v@^OO9F

[10] Lempert, R. (2020). Robust Decision Making. 2020 DMDU Webinar Series, The Society for Decision Making Under Deep Uncertainty, 14 April 2020. https://itesm.zoom.us/rec/share/uclNAe_S51NOXpX3q2CHdas7AKnZaaa8gyZM_KEKzUfYdjlTgILb668oHBnLJhz Password: 3K#90jT1

# Annex C – SURVEY RESULTS AND ANALYSIS

The following appendices report results from a survey developed by the SAS-134 research task group: "Linking Strategic Investments and Divestments to Defence Outcomes." The survey was developed from an initial exploration of the literature relevant to Defence Investment Prioritization (DIP). The survey results are reported here in ten separate appendices that correspond to parts 0 – 9 of the survey. Each appendix contains response distributions and summary observations from the data.

The strategic nature of the topic has meant that full and accurate responses to all the questions require expertise unlikely to reside in a single community, since it probes both administrative and analytical domains. In some cases, the wide breath of inquiry and the number of different sub-organizations and positions responsible for aspects of portfolio review made the questionnaire too onerous and was the basis for nations declining to respond to the questionnaire. In others, nations were able to assemble a group of experts collectively familiar with a broader variety of perspectives on their nation's DIP process. In still others, the expertise of individual respondents may not have extended into all the areas explored, so that the reliability of the data collected varies to an unknown extent even within a single survey.[1]

We obtained survey responses from 13 nations and have attempted to present meaningful trends in the data and ways to report them without violating our promise to conceal identities of the respondents and their nations. We were able to survey 6 nations with populations greater than 20 million and 7 nations with populations fewer than 20 million, and this is the only subdivision we define within the group of surveys collected. Not all nations participating in SAS-134 completed the survey. Not all of the responding nations are members of NATO.

The survey was designed to probe the variety of national practices as fully as possible. Since creating and administering the survey, further review of the relevant literature revealed some unexpected insights that the survey results reinforce. However, we did not find as much application of operational research and decision analytic techniques as we expected. Perhaps the most significant survey takeaway is that PIP procedures vary widely between nations for good reasons, having been shaped by distinct national cultures, histories, experiences, and philosophies of government.

Nevertheless, this study identifies and proposes a universal set of principles that could underpin more sound DIP decisions and provide a more objective set of lenses through which nations can examine the features of their own DIP process. Then it is up to each nation to decide the extent to which application of some principles is lacking in their processes and how they might be adapted to better serve long-term defence outcomes for their nations and their allies.

[1] For one nation, we obtained two separate survey responses from experts in different aspects of the PIP process and undertook to combine them into a single national response.

# Appendix C.0: PLANNED INVESTMENT PORTFOLIO (PIP) PROBLEM SCOPE, SCHEDULE, ASSUMPTIONS, AND STAGES

All responding nations indicated that they develop and maintain a prioritized list of future capital investments, which are referred to in this study as a Planned Investment Portfolio or PIP. Questions in Part 0 of the survey focused on general features of the nation's PIP to establish a foundation to help understand actual practices of responding nations. Brief summaries of the responses appear below.

National PIP time spans (out-years) ranged from three to twenty years, divided into anywhere from one to five sub-periods. The reported time between PIP reviews ranged from annually, to every six years. Note that countries mostly adopt rolling multi-year plans which are revised each time a PIP review is conducted. For example, In the case of a country with a rolling five-year plan, if a PIP review is conducted annually, then a new (revised) five-year plan is developed each year reflecting updated information on the threat environment, new technology, financial crises, pandemics, etc.

**Table CA0-1: Length of Nation's PIP Time Spans.**

| Time Span | Nations |
|---|---|
| Less or equal to 5 years | 4 |
| 6 – 10 years | 3 |
| 11 – 20 years | 6 |

**Table CA0-2: Years Between PIP Review.**

| PIP Review Intervals | Nations |
|---|---|
| Annual | 5 |
| 4 years | 3 |
| > 4 years | 2 |
| When Gov't changes | 3 |

The longest time span considered in a PIP review was 20 years in two nations, with their PIP reviews conducted every four years, or based on government tenure. Not surprisingly, shorter PIP time spans were associated with shorter periods between PIP reviews.

The collection of respondent comments generally focuses on three PIP sub-periods. The first sub-period consists of building the following year's defence budget, which involves detailed costing for the next fiscal year, and multi-year funding forecasts. It also coincides with current budget execution and any necessary revisions of Defence Plans.

The second PIP sub-period includes Preparation (2 – 4 year time horizons) where cost estimates are less certain, combined with Acquisition Planning, and any necessary revisions of Defence Plans.

The third sub-period focuses on the most expensive and risky Investments, R&D and Acquisition, and any necessary revisions of Defence Plans.

As there were large differences with respect to PIP time spans, this must bear on what kinds of issues are included in a nation's planning process. For example, if a PIP stretches only a few years into the future, proposed investments under consideration are likely closer to implementation and therefore lend themselves to better cost estimates than may be the case for planned investments in the distant future (e.g., 10 years or more). Longer term investments under consideration can still be in an R&D phase or, if procured from abroad, not yet available, which makes cost estimates more uncertain. Compounding this uncertainty are questions about possible future changes in the defence environment which could impact the ultimate benefit generated by these longer term investments.

A synthesis of nations' responses reveals that stages of the PIP process largely reflect the spirit of the original Planning, Programming and Budgeting (PPB) System of USA. A distillation of several common stages is described below.

The first stage involves planning guidance instructions from the nation's Ministry of Defence (MoD) including assumptions about future threats, required capabilities, capability gaps, new technology, and other forecasts – including budget, personnel, and other constraints. Each component under the MoD establishes their "requirements" with some awareness of these constraints. An analysis is conducted of overall proposed Armed Forces Plans. Assessments are conducted on what has changed since the last review and data is collected on investment alternatives (including project descriptions, year-over-year costs, and stated requirements) to satisfy capability gaps. A draft plan is prepared by the Defence Chief of Staff.

The second stage links Plans and Desired End-States. It validates and evaluates investment data and DOTMLPFI analyses to develop portfolio options. Military departments submit proposals for additions/modifications along with system requirements. A second round of discussions matches requirements and financial resources (trade-offs between capabilities, in terms of quantity and quality), along with Strategic Reviews of External Risks. The draft PIP (including materiel acquisitions and expected capabilities) is based on operational requests and rough cost estimates.

The third stage involves a capability, concepts and program review by senior leadership and analysis of operating budget requirements. Technical opinions are solicited from Armament Directorates. Initial balancing of the PIP and baselining it to the budget is followed by discussions of portfolio options with leadership and revisions as required. Once requirements and resources are aligned within each authority/subordinate, the PIP military planning law proposal is sent to the Cabinet of the Minister for their decision (validation, trade-offs, etc.).

The fourth stage prioritizes budget allocations. A draft PIP assigns priorities and establishes funded programs, and those in reserve. The Council of Ministers endorse the PIP military planning law and sends it to inter-ministerial authorities (ministry of finance, etc.), possibly for comment by the executive branch (president), and the treasury. The contents of the portfolio are approved for submission to central agencies. Military Departments submit detailed budget estimates for the next fiscal year.

The latter PIP stages involve the final development of portfolio alternatives, careful cost estimation for the first fiscal (budget) year, and a detailed budget review. Final reviews including the Chiefs of Staffs of the Armed Forces, and Technical and Legislative Departments (where new requirements may emerge and require PIP re-prioritization) are conducted leading to approval by the Minister of Defence.

Above the level of National Defence, once final inter-ministerial, Treasury and Prime Minister (President) approval is granted, the PIP's first fiscal year budget proposal is submitted to Parliament (Congress) for a vote to enact into law. Note that the internal multi-year MoD PIP may differ from politically approved framework agreements. The politically approved PIP produced by the MoD is an input into the Government Defence Report (White Paper) and Budgetary Planning. Parliaments (Congress) authorize, and provide/appropriate funds distributed to the MOD for the first (budget) year of the finalized PIP. Subsequently the MoD executes

the approved fiscal year budget and can only amend the PIP within strict limits. An investment board/committee may approve or require changes based on consultation with relevant stakeholders.

In terms of capabilities, nations indicated their PIP included all capabilities, with the exception that intelligence is not included by one nation. In addition to this, some nations clarified their response options as follows: most R&D is in a separate planning process; the process does not include investment under a certain threshold value; and property (military construction) investment is planned separately with its own constraints but closely connected. Finally, one nation indicated they maintain more than one PIP.

Figure CA0-1, below, reveals other items considered in the investment planning process alongside major equipment acquisitions. Corresponding to the concept of investment in a "Total System," roughly ½ the nations included force size considerations in their PIP process. Roughly 2/3 reported that in addition to equipment/platform procurement/acquisition all items in Figure CA0-1 are also included in a PIP (Upgrades, Software, Construction, etc.), while the remaining 1/3 indicated their primary focus was exclusively on major capital Equipment/Platforms.

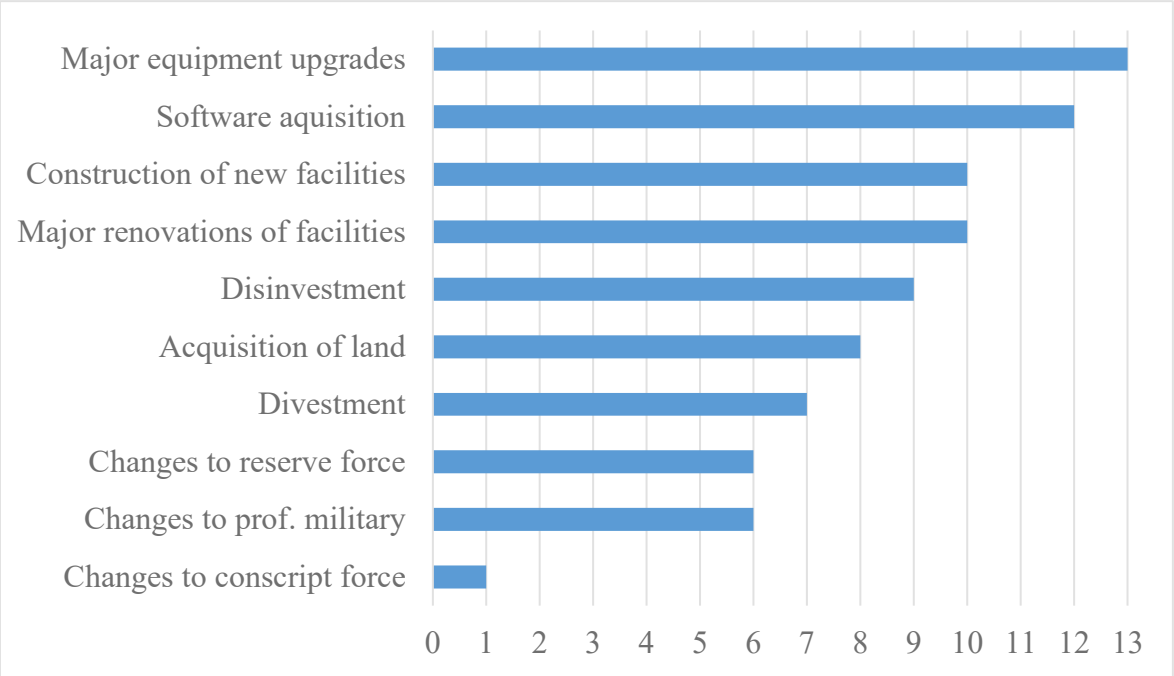



**Figure CA0-1: In Addition to Major Capital Equipment, the investment Planning Process may Include Other Items (Note: bar graph indicates number of nations that include a particular item in their PIP process).**

Meanwhile, all nations agreed major upgrades were included in a PIP. Nearly all responding nations also included Software development. Ten of the 13 nations included facility construction and upgrades. Cancelling of ongoing projects (disinvestment) is included by nine countries, land acquisition in eight countries, and the retiring of equipment (divestment) in seven countries.

Six nations prioritized changes to the military force structure (both professional and reserve) in the DIP process, while changes in reserve forces are considered by one nation that maintains a conscript force. Changes in the size of the force are another consideration: as one nation commented, proposed changes to force size can result from the DIP process but are executed outside of it.

## CA0.1 Summary

Today defence officials face urgent decisions on which investments to include in their defence portfolios. Finding the optimal mix to meet national and alliance requirements is the heart of the defence planned investment portfolio problem. The survey results suggest countries largely follow the spirit of the US's Planning, Programming, and Budgeting System (PPBS) which was designed to facilitate defence resource allocation decisions.

The first two steps in NATO's Defence Planning Process (1. Establish Political Guidance; 2. Determine Requirements) reflect the Planning phase of PPBS; and the third (3. Apportion Requirements and Set Targets) reflects the Programming phase. The goal of multi-year "programming" parallels the Planned Investment Portfolio (PIP) problem. It ensures nations build and maintain a cost-effective mix of forces that maximize national (and collective) security subject to forecasted budget constraints. The Budgeting phase simply translates those decisions into an annual budget submitted to Ministries of Finance, the Prime Minister and President for approval and review by Parliaments/Congress.

## Appendix C.1: THE SOCIO-TECHNICAL DECISION PROCESS

This part of the survey explores the decision process used by nations to develop their Planned Investment Portfolios or PIPs.

The responses reveal significant diversity in approaches, although most nations reported they use some form of Dialogue Decision Process (DDP). This approach is defined in the survey as "a sequence of meetings between a team of decision makers and stakeholders and a team of analysts together executing defined stages in the (re)formulation of a PIP." Some nations also reported using Decision Conferencing (DC), defined in the survey as "a set of meetings attended by decision makers and all key stakeholders in which a skilled facilitator leads the group through the (re)formulation of a Planned Investment Portfolio."

As indicated in Figure CA1-1, ten nations specifically reported using the DDP. Four nations reported using DC, and two nations Consensus Modelling, which the survey defined as "tools that aid negotiation toward consensus by showing the degree and character of stakeholder agreement or disagreement."

Of the four nations that explicitly indicated they used DC, all agreed that their DC included *Facilitated development of portfolio value criteria, value modelling and calibration*. Three nations said it included *professional facilitation*, and two that it involved a *continuous display of the results*. Although not explicitly indicating they used DC, two other nations nevertheless responded to DC-specific questions and selected *Facilitated development of portfolio value criteria, value modelling and calibration.* (See Figure CA1-2.)

Although no nation that explicitly indicated use of DC in building a PIP reported they include participants from government outside of ND, two other nations reported they do include officials from outside ND. (See Figure CA1-3).

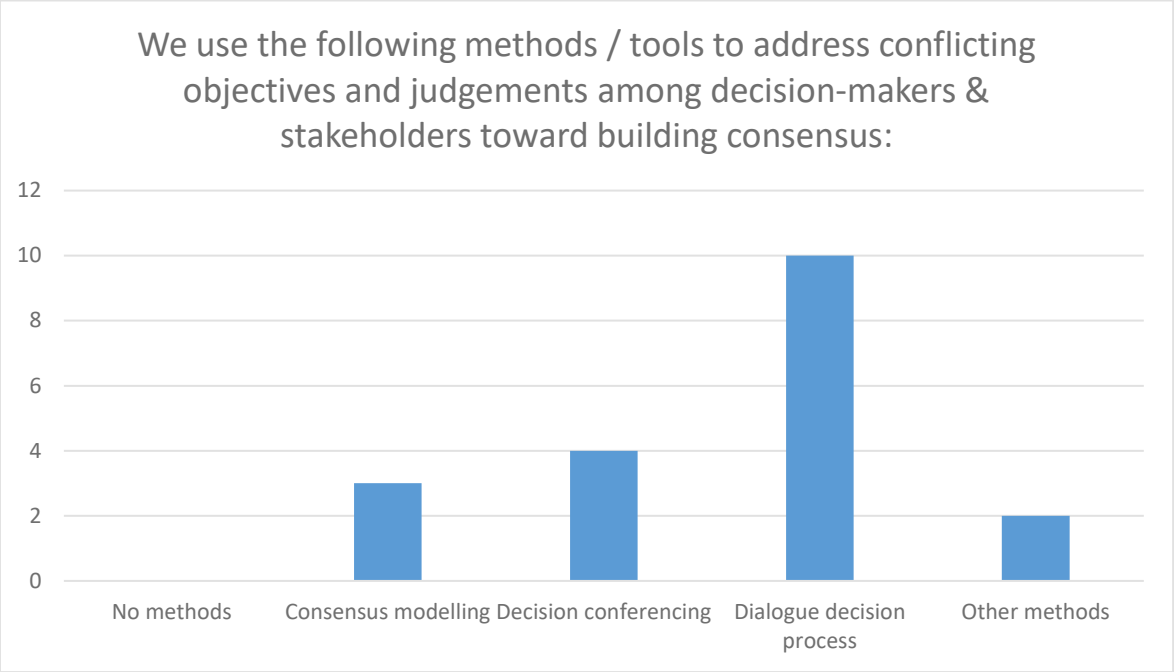



**Figure CA1-1: Approaches to Build Consensus in the Development of a PIP.**

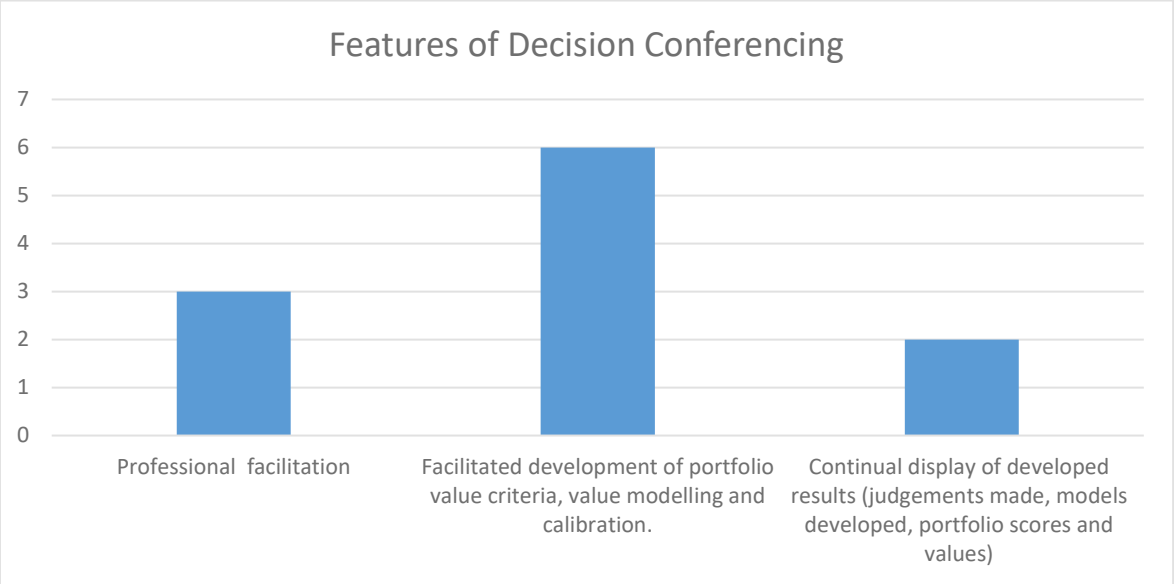



**Figure CA1-2: Characteristics of the PIP Decision Process.**

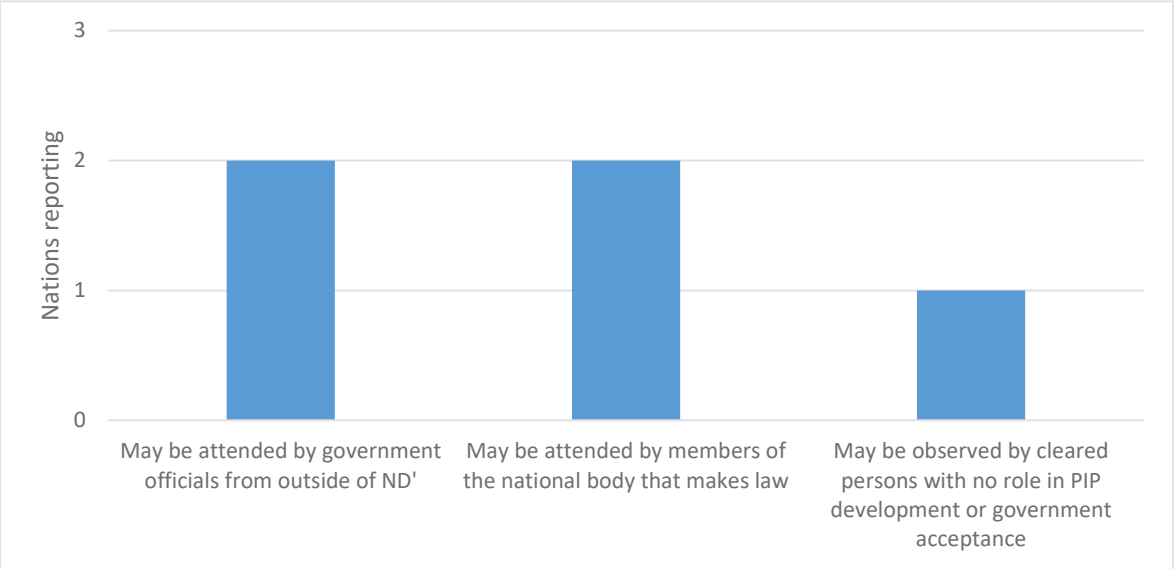



**Figure CA1-3: Inclusion of Outside Observers in the PIP Process.**

In Figure CA1-4, four nations that explicitly indicated they use DDP to build a PIP report that decision team and analysis team membership is stable throughout the process. Interpreting DDP more broadly, six of thirteen nations indicated they had stable team membership throughout their development of a PIP. Three of thirteen report that PIP development follows a standardized strategic decision model used across ND for strategic decision making and also that roles are well-defined. Surprisingly, no nation indicated they train personnel for these roles.

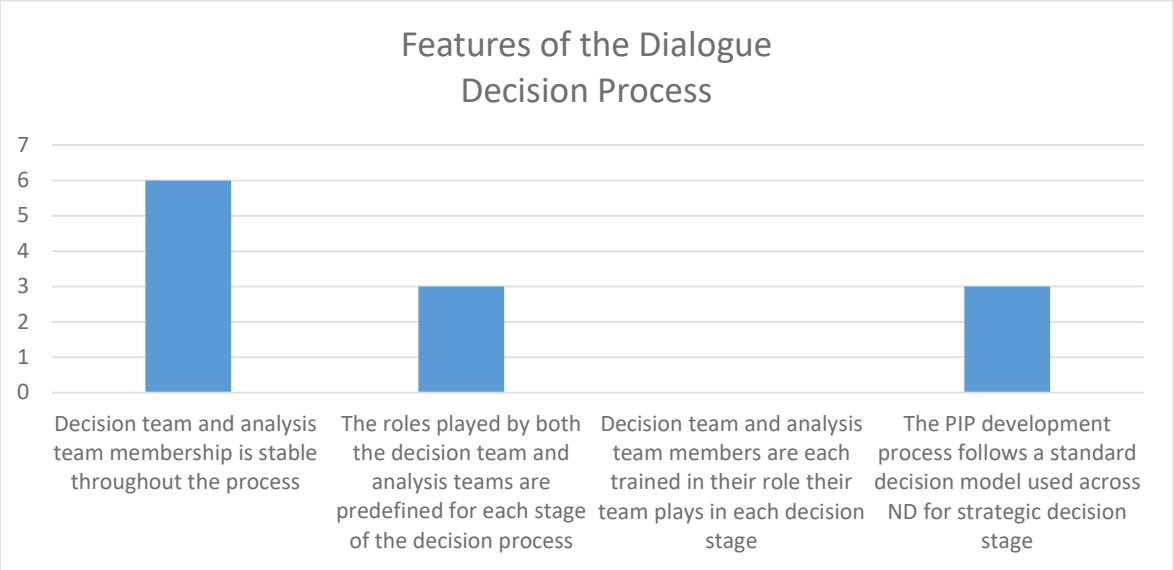



**Figure CA1-4: Features of the PIP Decision Process.**

In response to statements that stakeholder preference data collected during PIP development was stored for future reference, was available while the PIP is undergoing approval and was available after PIP approval, resulting response distributions were as shown in Figure CA1-5.

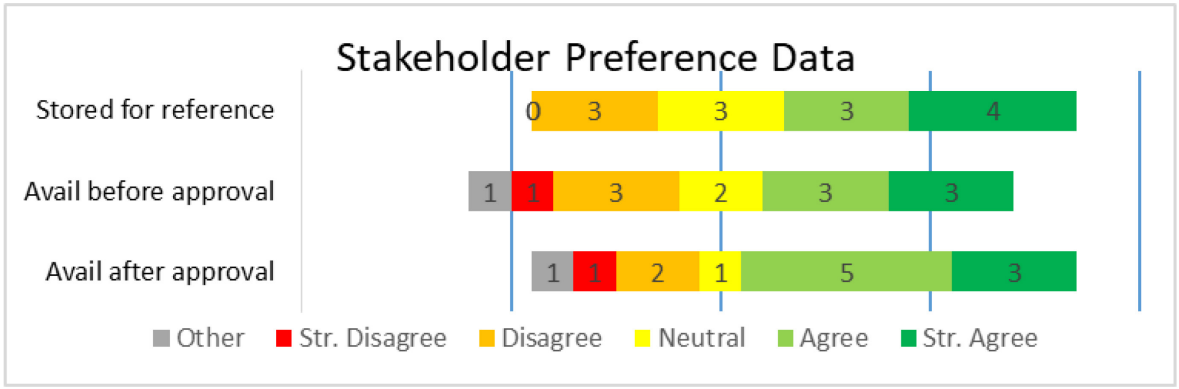



**Figure CA1-5: National Responses that Collected Stakeholder Preference Data was Stored and Available.**

Nations were asked about the size of the ND body that approved the PIP. Figure CA1-6 reveals that senior ND approval of a PIP comes from a single decision maker in five nations. The other respondents reported PIP decision making bodies in ND that include three or more individuals. Nearly every nation indicated the chief of defence has an important role.[2] Moreover, comments from nations state that more costly project decisions are raised to a political level (MOD to Parliament). In fact, it is reasonable to conclude that in most nations, major equipment decisions in a PIP routinely involve interactions between politicians and the military.

[2] Only one country reports the PIP-approval authority is below the level of Chief of defence.

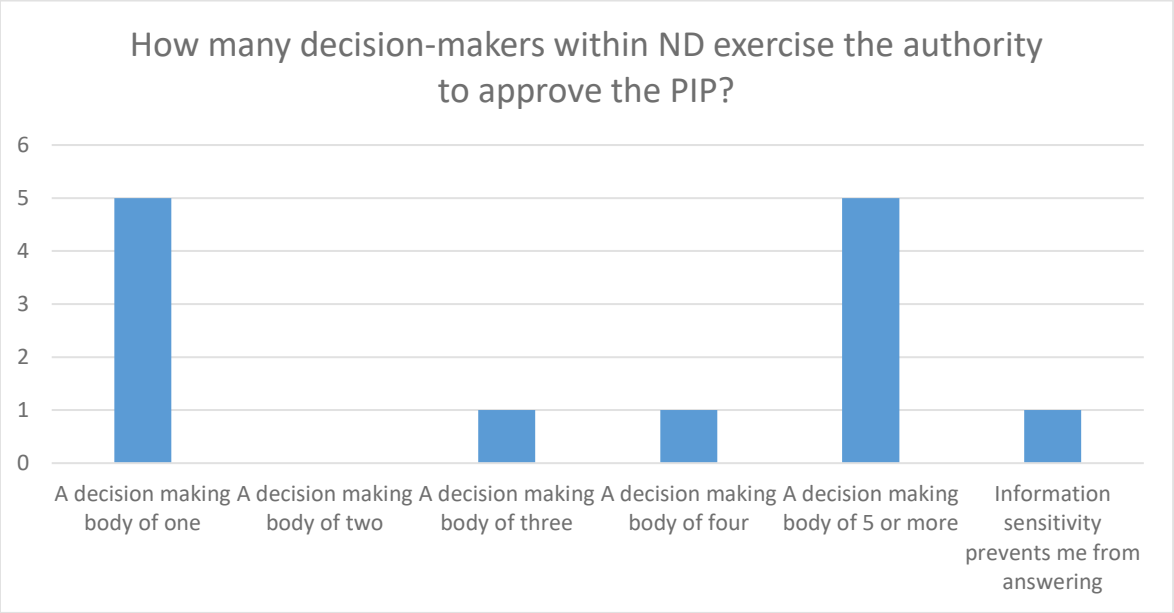



**Figure CA1-6: Nations that Rely on 1, 2, 3, 4, or Five-or-More Decision Makers for Final PIP Approval.**

## CA1.1 Summary

Answers in this part of the survey reveal a great deal of diversity among responding nations. The diversity of responses could arise from a variety of factors including: the size of a nation's defence forces, its political system, and the degree of political influence over defence investments, laws, and regulations. The diversity could also stem from varying cultures, methodological traditions, and analytical maturity.

Nevertheless, most nations (76%) in the survey reported they use a form of Dialogue Decision Process (DDP) in their PIP decisions. This suggests they have a sequence of meetings involving teams made up of decision makers, stakeholders, and analysts, who together are involved in various stages of the development of their Planned Investment Portfolio (PIP). The survey also reveals significant differences in the maturity of the process, including the use of formal methods, how well roles and various steps in the process are defined, and the extent to which stakeholder preference data is stored and utilized.

## Appendix C.2: PORTFOLIO FRAME INCLUDING OBJECTIVES, SUB-OBJECTIVES, CRITERIA, AND METRICS

Part 2 of the survey explores the extent to which nations frame their Planned Investment Portfolio (PIP) decisions. The frame defines the nature and boundaries of the decision, what is to be decided, and what the decision is to accomplish.

The sequence of questions begins by exploring whether decision maker and stakeholder preferences and priorities for the PIP are collected; then whether preferences and priorities are translated into portfolio evaluation criteria, (and if so) whether the criteria take the form of specific end-state objectives, (and if so) whether those objectives are collectively exhaustive and whether they are decomposed into sub-objectives; whether end-state objectives are as mutually exclusive as possible, and then whether they look for causal relationships between objectives. Finally, we explore whether nations use portfolio metrics to compare alternative portfolios and, if so, are metrics anchored to portfolio criteria (see Figure CA2-1). This reflects a top-down analytic approach from goals to abstractions that enable measurement of portfolio merit against goals.

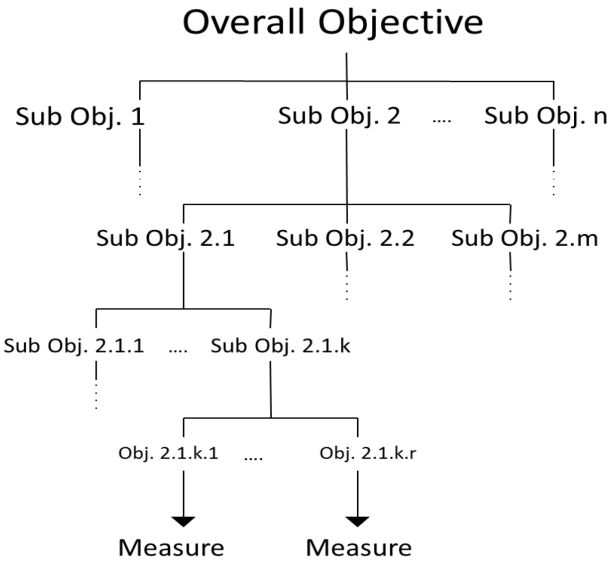



**Figure CA2-1: Example of an Analytic Hierarchy Approach for an End-State Objective.**

Ensuring objectives are collectively exhaustive (include all relevant end-state objectives), and that criteria and metrics are mutually exclusive (to avoid double-counting), can offer a valuable guide to help evaluate the extent to which end-state objectives are achieved by alternative portfolios. Combined with portfolio costs and budget forecasts, the development of end-state objectives, sub-objectives, criteria, and measures of effectiveness can help guide decision makers to better informed PIP decisions.

The green bars in Figure CA2-2 indicate the number of countries that agreed or strongly agreed they followed steps in the analytic approach described above.[3] For example, ten countries indicate they solicit preferences

[3] Figure CA2-2 presents the numbers of responses to each question of each type (labelled with response counts) on horizontally stacked bars. The bars are shifted horizontally until all the responses of "Neither agree nor disagree" (shown in yellow, if any) fall on the same vertical line. In this way, a glance reveals whether there were more agreeing responses (green, to the right) or disagreeing (orange or red, to the left). Responses other than those from the Likert-type menu are tabulated as N/A for not applicable.

and priorities from PIP decision makers and participating stakeholders, five tending to agree and five agreeing strongly. Clarifying comments suggest the focus may be on what has changed, capability gaps, and risks.

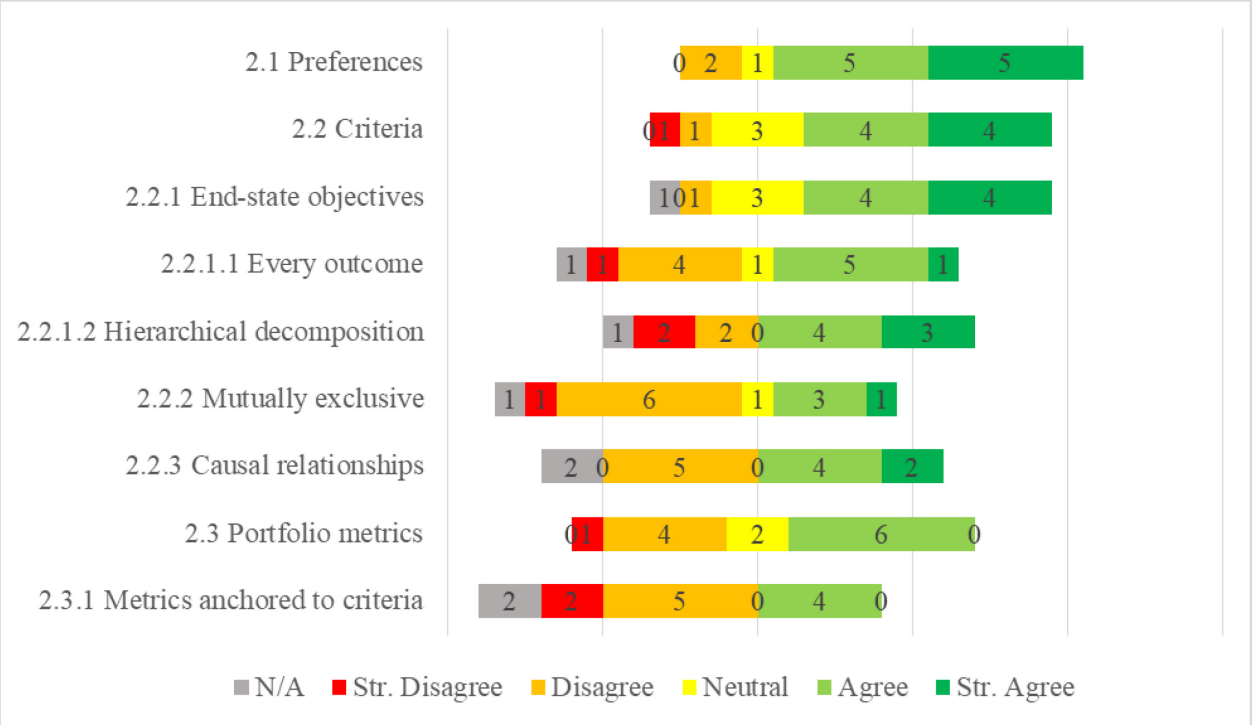



**Figure CA2-2: Responses to Part 2 of the Survey.**[4]

Six countries reported end-state objectives they develop are collectively exhaustive (i.e., include every desired outcome) (Section 2.2.1.1). Interestingly, one nation revealed their objectives are "sequentially exhaustive" as new objectives and criteria are discovered through the PIP process over time.

Seven countries report they decompose end-state objectives hierarchically into component sub-objectives. (Section 2.2.1.2) Eight nations agree they develop a set of criteria to evaluate the merit of combined PIP investments, and also that these criteria relate to ND end-state objectives (Section 2.2, Section 2.2.1). However, only four nations report their criteria/objectives are mutually exclusive (Section 2.2.2).

[4] Several patterns can be seen in the response distributions shown in Figure CA2-2:

1) As questions proceed from the general to the specific;
   a) Responses shift away from agreement and toward disagreement, seen in the shift from the green at the top-right (10 agreeing, 2 disagreeing) toward red at the bottom left (4 agreeing, 7 disagreeing);
   b) Responses shift from initially stronger agreement or disagreement more toward tendencies of agreement or disagreement, seen in the shift from more darker colours at bar ends (initially 4 or 5) toward fewer more dark colours (1 or 2 strong); and
   c) Responses shift away from Likert-type responses toward "Not Applicable" responses, seen in the gradual emergence of more grey segments on the left at the bottom than at the top (initially 0 but reaching 2 in the last and third last).

These are somewhat unsurprising in questions that shift from the general to the specific. Later questions are worded in a way that presumes the truth of earlier statements, making these trends more likely. Question 2.2.1.1 is quite specific and shows only two strong responses. It refers to being "collectively exhaustive" and including "every outcome," confirming the noted trend.

Six nations indicate they attempt to identify causal relationships between PIP sub-objectives. (Section 2.2.3) Clarifying comments acknowledge the challenge of mapping interdependencies, and the importance of understanding key linkages required for "systems of systems."

Finally, six nations report they attempt to develop portfolio metrics to help distinguish the comparative benefits and costs of alternative investment portfolios, but only four report their benefit metrics are tightly anchored to PIP criteria. (Section 2.3 and Section 2.3.1) For instance, one nation indicates its main metrics focus on PIP feasibility (market acquisition/development realities, preferably with strategic partners), and the availability of personnel. Interestingly, the clarifying comments suggest that, if metrics are used, they are mostly applied to inform decisions at the individual program or project level, and less so at the portfolio level.

## CA2.1 Summary

Combined with portfolio costs and budget forecasts, the development of end-state objectives, sub-objectives, criteria, and measures of effectiveness can help guide decision makers to better informed PIP decisions. Whereas there appears to be appreciation for the utility of developing and applying detailed, comprehensive, and mutually exclusive portfolio objectives in terms that can be measured, the responses of nations reveal multiple challenges in fully implementing this approach.

## Appendix C.3: COMBINING PIP EVALUATION CRITERIA AND METRICS

Part 3 of the survey explores how nations approach the problem of evaluating alternative Planned Investment Portfolios (PIPs). The questions were designed to reveal whether nations tend to use a more quantitative or qualitative approach. Criteria typically used to help evaluate alternative PIPs include costs, benefits, and budgets/financing.

While Figure CA3-1 indicates seven nations agreed or strongly agreed they develop and use **metrics** that measure the extent to which a candidate portfolio satisfies PIP criteria, accompanying comments suggest quantitative metrics mostly relate to constraints on the PIP, including available resources (personnel, etc.) and financing/budget limits. An example of a widely used quantitative approach would be the development of metrics (*cost* estimates) to ensure a PIP does not commit more funds over its time horizon than is likely to be available.

In sharp contrast, responses reported in Figure CA3-1 suggest most nations recognize their attempts to capture the *benefits* of alternative portfolios tends to be more qualitative. For example, while four nations tend to agree that they report they combine metrics using a **value function**, and two that they use a **weighted sum** to measure benefits, clarifying comments suggest these approaches are mainly used to evaluate benefits of individual projects or investments, but not applied to the entire portfolio. For example, while nations might use value functions within a military program (intra-program analysis), they are not applied across programs (inter-program analysis).

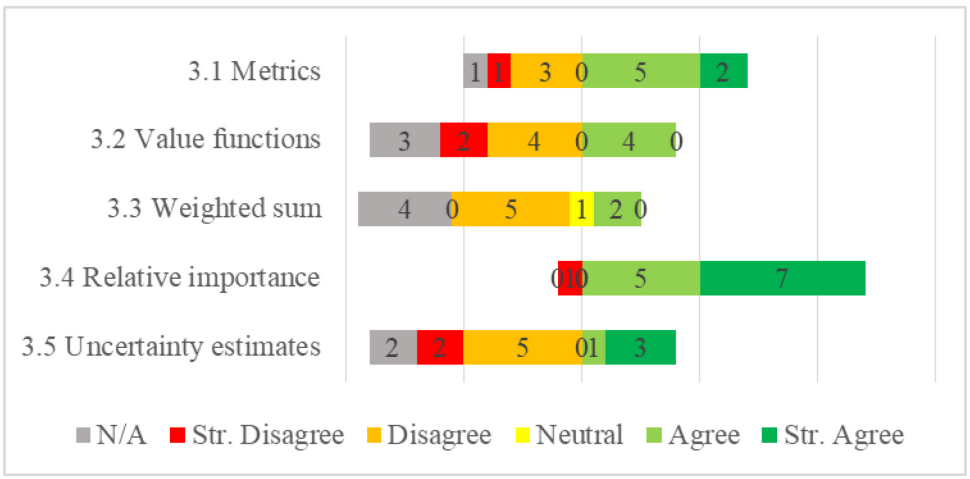



**Figure CA3-1: Approaches to Evaluate Alternative Planned Investment Portfolios (PIP).**[5]

The challenge (complexity) of developing quantitative benefit metrics and combining them using some value function to evaluate portfolios explains why nearly all (twelve) nations agreed they ask decision makers and participating stakeholders for their judgments regarding the **relative importance** of different types of benefits promised by a portfolio. Accompanying comments suggest this qualitative approach to solicit subjective value assessments can be supported through experimentation / wargaming.

[5] Part 3 solicits Likert-type responses indicating agreement or disagreement (Strongly disagree, Tend to disagree, Neither agree nor disagree, Tend to agree, Strongly agree) with each of five statements regarding the respondent nation's use of portfolio metrics to model the benefits associated with alternative prioritizations determining the content of their Planned Investment Portfolio (PIP).

Surprisingly, only four nations report they **estimate** any **uncertainty** associated with their evaluation of candidate portfolios. An interesting comment suggests one way to estimate uncertainty may simply be to consider the level and experience of participants, and their ability to make value judgments that are "repeatable and defensible."

Finally, investing in more formal analysis may be more attractive as the number and complexity of investment options increases. Since this is more likely to be the case in larger nations than smaller ones, the hypothesis is tested that response distributions of larger nations show greater agreement with the statements in this part than do smaller nations. The results reported in Table CA3-1 appear to support the hypothesis that larger nations tend to use more formal methods.

**Table CA3-1: Mann-Whitney U Test: Larger Nations Implement a More Formal Value Modelling Strategy.**[6]

| | Strongly Disagree | Disagree | Neither | Agree | Strongly Agree | Count | U | Z | p |
|---|---|---|---|---|---|---|---|---|---|
| **Larger Nations** | 1 | 10 | 1 | 9 | 9 | 30 | 253 | -1.660 | 0.0485 |
| **Smaller Nations** | 5 | 7 | 0 | 8 | 3 | 23 | 437 | | |

## CA3.1 Summary

The questions in Part 3 of the survey were designed to reveal whether nations tend to use more quantitative or qualitative approaches in evaluating alternative PIPs. Criteria typically used to help evaluate PIPs include costs, benefits, and budgets/financing. There is some agreement about the use of quantitative analysis when it comes to cost and financing/budgets, but despite the growing importance of formal benefit/effectiveness measures at the project or individual investment level, it appears most nations use more qualitative and subjective assessments at the portfolio level.

[6] Using a one-tailed Mann-Whitney U Test (also called the Wilcoxon Rank Sum Test) on the two aggregated response distributions shows that the probability of seeing rank sums this different by chance is about 4.8%

# Appendix C.4: BENEFIT MODELING

The challenge that faces nations in their attempt to measure the benefit or effectiveness of alternative portfolios was clearly illustrated in Part 3 of the survey. Part 4 of the survey presented respondents with a variety of tools and techniques from the literature to determine the extent to which these are used to model the benefit derived from a particular portfolio. This part explores which (if any) of these tools and techniques were applied by survey participants. A selection of 16 tools and techniques were selected that reflect best practices discussed in the literature (see Figure CA4-1, and Appendix B.5 for brief descriptions of most of these terms). These tools and techniques can be applied individually or in combination, although some cannot be used within the same process at the same time, so not every grouping is feasible.

As can be seen from (the yellow sections of bars) in Figure CA4-1, when these tools and techniques are used, they are typically only applied "indirectly." This implies some countries have borrowed ideas and concepts from various tools and techniques and incorporate them into their own methodology. More than half the countries (8 out of 12) report at least one tool or technique as being either "directly related" or "used" by that country in its benefit modelling. Only one country indicated that it used none of these techniques (even indirectly), and indicated it used a different methodology.

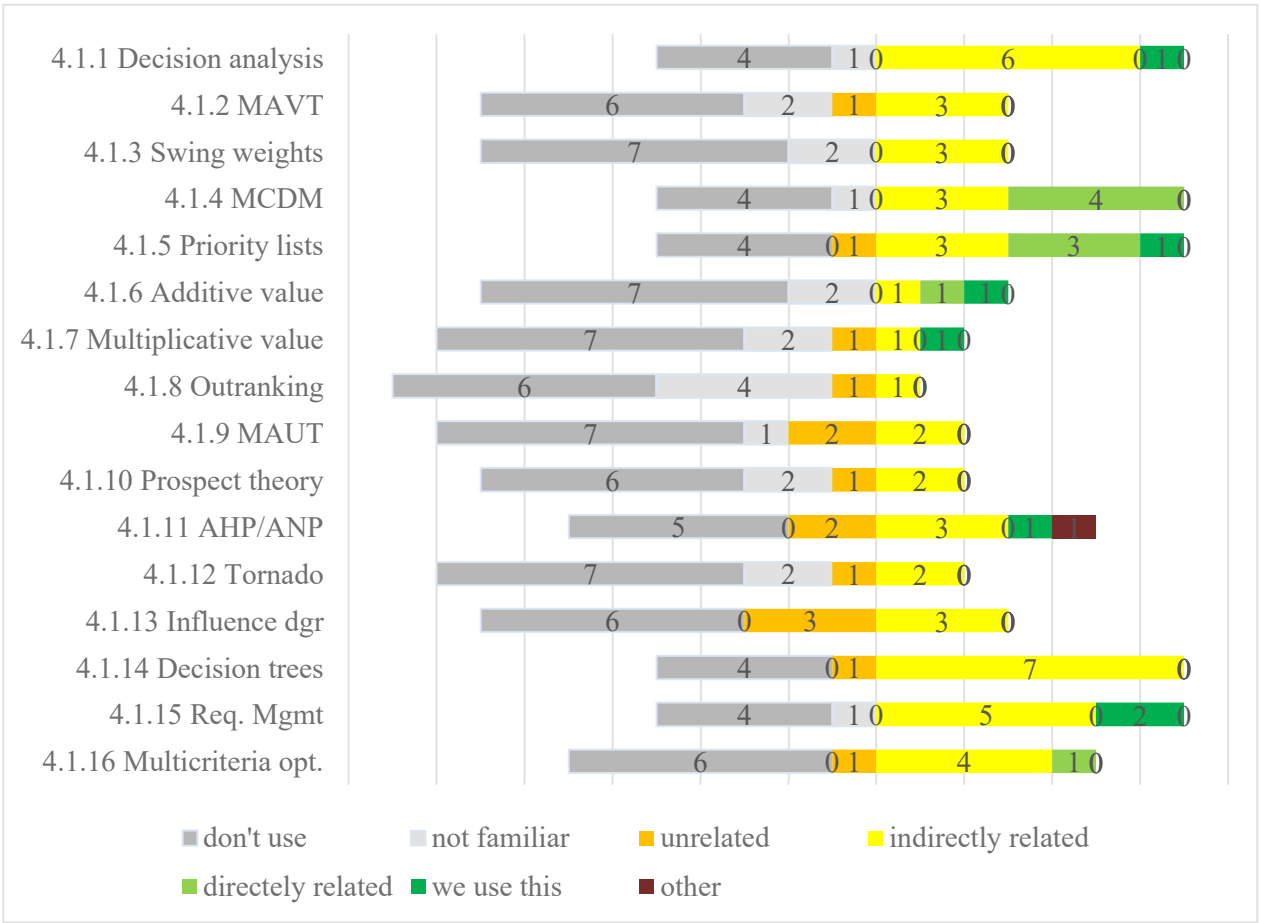



**Figure CA4-1: Nations Use of Tools and Techniques in the Literature.**[7]

[7] The bars in the graph have each been centred at the unrelated/indirectly related boundary.

The most commonly used tools (each with 7 mentions) were:

- Decision Analysis (Value Focused Thinking) (6 Indirectly, 1 Used);
- Multi-Objective / Multi-Criteria Decision Analysis / Decision Making (MODA / MCDA / MCDM) (3 Indirectly, 4 Directly);
- Priority Ranking (3 Indirectly, 3 Directly, 1 Used);
- Decision Trees (7 Indirectly); and
- Requirements Management (5 Indirectly, 2 Used).

Multiple Criteria Optimization (4 Indirectly, 1 Directly), and AHP/ANP (3 Indirectly, 2 Used), were the next most popular with 5 mentions apiece.

One country was a full adopter of these benefit modelling techniques. It could be that this country is actively experimenting with these techniques over time since some cannot, and/or are highly unlikely to, be implemented simultaneously. Aside from the full adopter country (which listed 5 of the tools as being in use), only Decision Analysis and Requirements Management were listed as being in active use at the national level.

Interestingly, Priority Ranking and Multi-Criteria Decision Making were both listed (by 3 and 4 countries respectively) as being directly related to the way those countries modelled portfolio benefits. Although tools and techniques varied across countries, four of the eight countries that reported at least one tool or technique as being either "directly related" or "used" employed a Priority List in their benefit modelling. Aside from the full adopter, all but one of the remaining countries report they use at most one or two of these modelling tools and techniques.[8]

## CA4.1 Summary

Even within this group of knowledgeable respondents, it appears tools and techniques drawn from the literature for this part of the survey are not well known. If benefit modelling is explicitly performed, it appears details of the benefit modelling process are mostly left to subject matter experts and analysts at lower levels of the organization, and that higher level decision makers are often largely unaware of how this was done. Given the accompanying comments, it appears this lower level analysis does not always inform the PIP decision-making process. It appears benefit modelling is relatively loosely addressed at the portfolio level and is not standardized within or across nations.

Examining the results and accompanying comments in detail it becomes clear that different tools and techniques are applied at different levels of the defence organization. Lower levels appear more likely to implement more quantitative and established analytical tools and techniques than higher levels of the organization. If they are conducted at all, any analytical assessments of benefits from lower levels appear to be viewed as "informational" or as "guides" for consideration by senior decision makers at the portfolio level.

No country in our sample has mandated the use of any of these tools and techniques. Of the 16 tools and techniques, only 5 appear to be well known and influencing benefit modelling practices. It appears that if a tool or technique is applied, then it is generally only applied indirectly, and serves as an informal guide to the benefit assessment process which remains largely an exercise dominated by more qualitative approaches. This suggests there may be an opportunity for nations to invest in exposing analysts and decision makers to some tools and techniques developed in the literature, and that this might improve estimate of benefits that might be gained from different planned investment portfolios.

[8] Note there does not appear to be any pattern among the countries in their use (or non-use) of these techniques in terms of size of country, size of budget, geographical location, or primary language.

# Appendix C.5: COST MODELLING

This part of the survey explores cost categories included by nations in their Planned Investment Portfolio (PIP) budgets. The concept of Total System or Total Cost of Ownership emphasizes the importance of including all relevant costs required to successfully deploy/operate assets included in a PIP. The set of Life-Cycle Cost categories for new investments typically found in the literature include Research and Development (R&D costs), Production/Procurement (Cost of Purchase), Operations and Support/Maintenance (Operating costs), and Disposal (End-of-Life Cost/Benefit). (For example, see Chap 5, p.113 in Melese et al. (2015) [1]).

In addition to these four standard cost categories, the survey inquires whether nations include eight additional cost categories in their PIP that may be necessary to successfully deploy/operate portfolio investments: Costs of Information Systems (IT); Manpower costs (Personnel); Training costs (Training); Costs of Real Property (Facilities); Administrative/Overhead costs (Project Management); Mid-Life Upgrades (MLU); Transportation costs (Logistics); and Transition costs (Transition). The green bars in Figure CA5-1 report the number of respondents that include each cost category in their PIP.

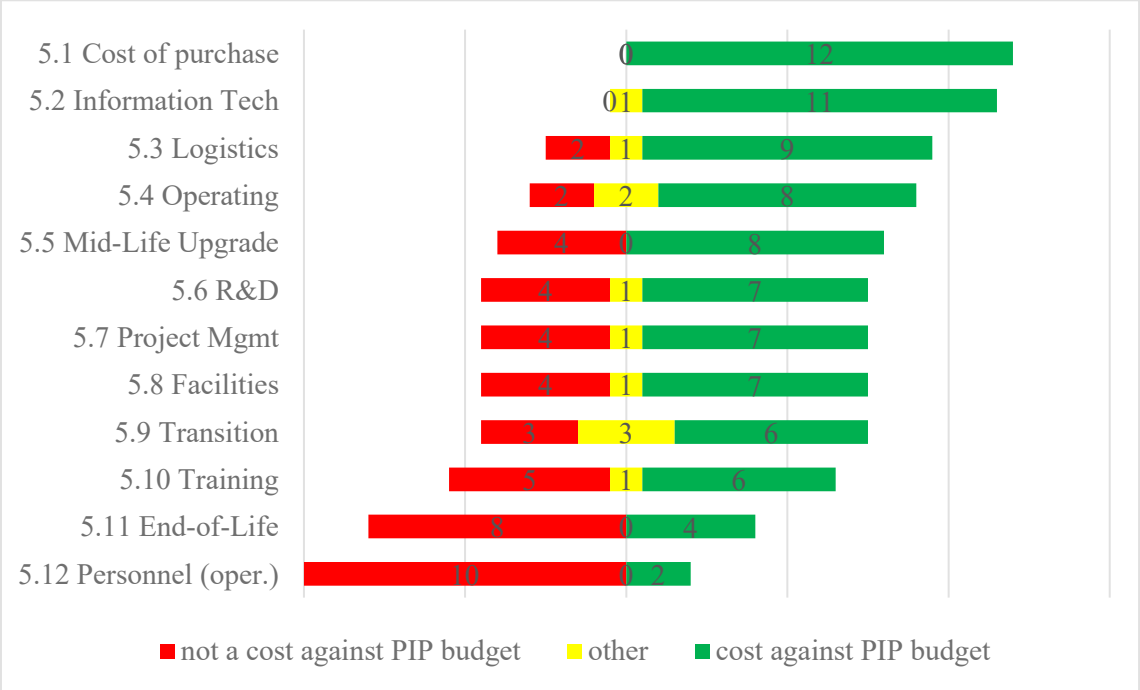



**Figure CA5-1: Costs Included by Nations in their Planned Investment Portfolio.**

As expected, all twelve respondents include the purchase price (Cost of Purchase) of new systems in their PIP budget. While only ten indicate they include Research and Development (R&D) costs, the accompanying comments suggest some equipment investments are expected to be purchased "off-the-shelf" so that R&D costs may already be incorporated in the purchase price.

Seven respondents indicate they include future operating costs (Operating) in their PIP budget estimates. However, one nation that selected "other" indicates operating costs are considered in parallel and funded in a separate account. Another nation commented that they only include spares for an initial, warranty-like period. Meanwhile, a nation that selected "no" nevertheless reveals it does include spares costs, but only up to the next expected Mid-Life Upgrade (MLU). Other nations commented that some, but not all, elements of operating

costs are included in their PIP. It appears most respondents do in fact recognize the importance of including at least some operating costs in PIP budget estimates (or in parallel accounts).

Since PIP time frames are generally shorter than the expected operational life of new systems, it is not surprising only four nations factor disposal (End-of-Life) costs/benefits in their PIP estimates. Whether or not end-of-life costs were included appears to be influenced by the length of a nation's PIP planning horizon. Nations with longer planning horizons tended to include these costs. The majority with shorter PIP time horizons did not.

Information systems (IT) that support portfolio investments were included by all but one nation. However, even the lone dissenter explains some required IT is included in the PIP, while the remainder is considered in a separate account.

Only two nations include costs of operating personnel (Personnel) in their PIP, while ten did not. Whereas operating personnel are clearly a significant factor in the future operational success of PIP investments, they may be a relatively small component of overall costs of new systems. Yet six respondents indicate they do capture training costs (Training) in their PIP budget estimates, which could include simulators, initial external training, etc. Some nations explained that personnel costs are considered elsewhere in the planning process, and/or in connection to the PIP, but are not included as a direct cost element in PIP budget estimates. For example, one nation includes personnel costs in their total cost of ownership estimates, but not directly against project/investment funding in their PIP budget estimates. Another respondent noted that personnel costs are only indirectly considered in new investments with the exception of manning new ships.

New investments often require the modification of existing, or construction of new, real property/structures (Facilities). For example: docking facilities for ships, hangers to house new UAVs, or maintenance facilities for new armoured vehicles. Seven respondents indicate they include this as a cost category in their PIP budget estimates. Seven nations also include estimates of additional administrative costs (Project Management) that might be required to guide and support successful deployment/execution of the PIP.

Given shrinking product life cycles due to rapid technological advances, and accelerating product obsolescence from competitor nation investments, Mid-Life Upgrades (MLU) are likely to be of growing interest in PIP development. Indeed, seven countries responded they include MLU as a cost category in their PIP budget estimates. Extra transportation costs (Logistics) are another consideration that may be required for the successful deployment of portfolio investments. Eight nations include this cost category.

The final cost category involves paying for the transition from older/legacy systems to newer systems (Transition). Such costs are only included by five countries. However, at least one other nation considers transition costs in parallel, rather than directly, in their PIP budget estimates, and two others include a few but not all transition costs.

Finally, this part also included a question on how various cost categories are represented in the PIP (i.e., whether they are estimated as a as a single number or as a range of numbers). Approximately 55 % use a range of numbers, and 45% single numbers. A clear pattern emerged with some nations predominantly or even exclusively using single number estimates for every cost category, while the others tended to estimate costs as a range of numbers.

The risk associated with cost estimates is discussed in Part 8 of the survey. The cost estimation issue is further discussed in survey Part 8 which focuses on risk. It might be inferred that nations that use a range of cost estimates are attempting to capture uncertainty, while those using a single number may either ignore, or capture cost risks in different ways.

## CA5.1 Summary

This part of the survey explores cost categories included by nations in their Planned Investment Portfolios (PIP). The concept of Total System (or "Ownership") Costs emphasizes the importance of including all relevant costs required to successfully deploy/operate assets included in a PIP. The set of Life-Cycle Cost categories for new investments typically found in the literature appear to be mostly captured by nations, in addition to several other cost categories. A full accounting of all relevant costs associated with a PIP would increase transparency, improve decision making, and ensure full funding is available to guarantee the future success of approved portfolio investments.

## CA5.2 References

[1] Angelis, D.I. and Nussbaum, D. (2015). Cost analysis. In: F. Melese, A. Richter, and B. Solomon, (eds.), Military Cost-Benefit Analysis: Theory and Practice. Routledge: New York.

## Appendix C.6: MAXIMIZING VALUE FOR MONEY

This part of the survey explores how nations ensure military investments provide maximum "value for money." The objective of a PIP is to fill capability gaps. Various benefit/value criteria identified in the PIP process can offer concrete measures to assess how well capability gaps are filled. The challenge is to assess how different mixes of investments in a PIP satisfy benefit/value criteria needed to fill capability gaps given projected funding available over the time period of the PIP.

The first three questions explore how nations link candidate investments to PIP benefit criteria and recognize benefit/capability gaps. The last two questions explore whether countries apply two standard techniques from the literature to help select a PIP to maximize military benefits: Constrained Optimization – Selecting a PIP that maximizes Capabilities/Benefits subject to budgets and other constraints (Chapman Burk & Parnell, 2011) [1], and Real Options – Planning more investments in the PIP than there is available funding, with the intention to eliminate some based on future information obtained on the actual need for specific capabilities. (For example, see Chapter 11 [2] and Chapter 14 [3] in Melese et al. (2015)).

Four respondents indicated their country did not explicitly use PIP benefit criteria. However, Figure CA6-1 reveals that, of those that do, all but two (i.e., 8 respondents) tended to agree or strongly agreed that they do examine how various candidate investments in the PIP contribute to their benefit criteria (all investments to each criterion). Interestingly, only six respondents indicate they recognize potential benefit gaps that might exist in the investment inventory when too few candidate investments exist to help fill a specific benefit criterion. Six respondents also indicate they actively search for new candidate investments to fill those under-served PIP benefit criteria.

The final two questions relate to techniques countries might use to maximize "value for money." Eight responded favourably suggesting they seek investments that promise the greatest combined benefit within constraints (Optimization). For example, one respondent comments: "We…fulfil capability gaps…given monetary constraints…"

Eight respondents also indicate that, in initial stages of the PIP process, they may start with more investments than they know they will be able to fund, and plan to reduce this over time (Real Options). It can only be conjectured the other respondents believe additional priorities exist that are difficult to precisely define as "benefits," and that compete with (or may be more important than) maximizing specified PIP benefit criteria.

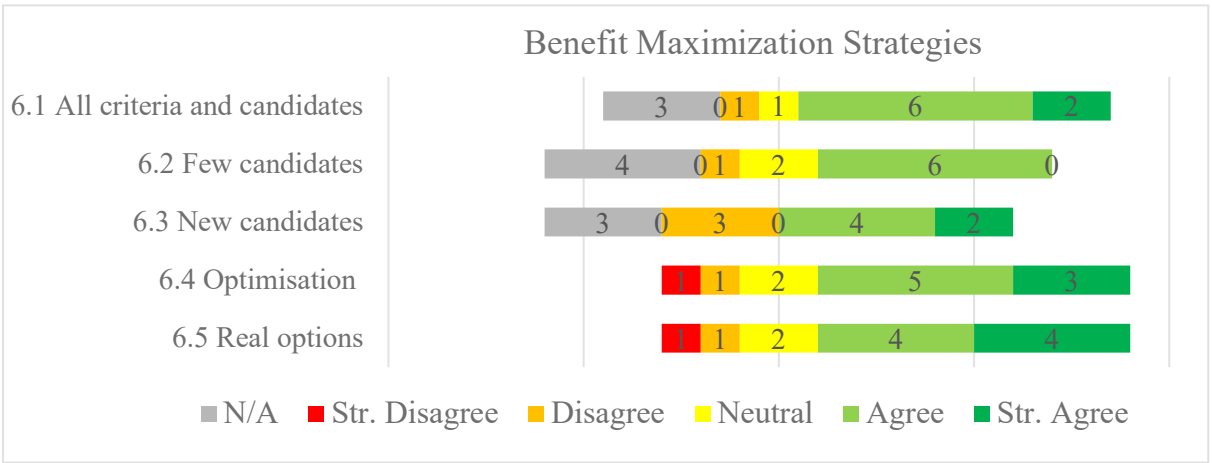



**Figure CA6-1: Managing the Investment Inventory to Maximize PIP Benefit.**

Interestingly, responses to the last two questions do not appear to have been focused on mathematical modelling per se, but instead on a broader more nuanced ("satisficing") approach to achieve an acceptable portfolio. Accompanying comments from several nations reinforce the fact that more subjective approaches are used to take decisions, rather than formal mathematical optimization methods. For example, one nation indicates they structure the problem for decision makers in terms of opportunity costs: They "test portfolios…for their relative performance, and…consider what would not be funded alongside what would be funded in the portfolio."

## CA6.1 Summary

This part of the survey focuses on different approaches nations use to ensure their PIP maximizes "value for money." It appears not all countries explicitly attempt to map contributions of candidate portfolio investments to neatly specified benefit criteria. While military benefits are an important criterion, other more subjective and difficult to measure criteria may influence the selection of candidate investments to include in a PIP. In fact, accompanying comments by several countries describe processes where capabilities and capability gaps are certainly considered, but not always explicitly in terms of any proposed PIP mapping to a well-defined set of benefit criteria. Interestingly however, several countries did mention they leverage unresolved capability/benefit gaps in their PIP to help make the case for additional funding.

Finally, the survey results and accompanying comments suggest portfolio benefit-maximizing strategies that are employed tend to be more ad hoc and include a process of deliberation, rather than involve the application of formal algorithmic/mathematical techniques. For instance, one country mentions that while "individual Departments may use optimization techniques in planning specific sub-portfolios (e.g., ground combat vehicles) …no such methods are applied to [investment trade-offs] across capability areas [at the portfolio level]." Even when benefits or benefit/capability gaps are explicitly considered, the complexity of the portfolio problem appears to drive nations to adopt a variety of approaches to help ensure their PIP provides military-value for money. In simple cases these approaches can be supported by standard textbook mathematical optimization techniques. With complex portfolios, the value of these techniques may be more conceptual.

## CA6.2 References

[1] Burk, R.C. and Parnell, G.S. (2011). Portfolio decision analysis – Lessons from military applications. In: A. Salo, J. Keisler and A. Morton (eds.), Portfolio Decision Analysis: Improved Methods for Resource Allocation, Springer: New York. https://www.researchgate.net/publication/226378345_Portfolio_Decision_Analysis_Lessons_from_Military_Applications

[2] Mun, J.C. and Housel, T. (2015). A risk-based approach to cost-benefit analysis: Strategic real options, Monte Carlo simulation, knowledge value added, and portfolio optimization. In: F. Melese, A. Richter, and B. Solomon, (eds.), Military Cost-Benefit Analysis: Theory and Practice. Routledge: New York.

[3] Angelis, D.I., Ford, D. and Dillard, J. (2015). Real options in military acquisition: A retrospective case study of the Javelin anti-tank missile system. In: F. Melese, A. Richter, and B. Solomon, (eds.), Military Cost-Benefit Analysis: Theory and Practice. Routledge: New York.

## Appendix C.7: INVESTMENT INTERACTIONS

This part of the survey explores investment interactions considered by nations as they build and evaluate their Planned Investment Portfolio (PIP). Possible interactions include investments that are: "*Complements*" – one investment requires another (or others) to operate successfully; or "*Substitutes*" – one investment can be used to fulfil the same requirements as another.[9]

Other possible interactions exist where investments offer: Positive "*Externalities*" – one investment offers spillover benefits that satisfy other requirements (i.e., overlapping investments might offer partial substitution, or some redundancy); or "*Synergies*" – where the value of combined investments is greater than the sum of their individual values. Another possible interaction is where two or more investments are sequential complements such that their joint success depends on "*Linked Execution*" – where the success (failure) of one is linked to the success (failure) of another.

Figure CA7-1 reveals eight respondents recognize investments that are "*Complements*" in their deliberations – or that one investment might require other enabling investments to deliver full benefits – but do not model the problem explicitly. Two countries add constraints in their PIP process to ensure they include complementary dependencies (or that necessary enabling investments accompany prioritized investments). Interestingly, two countries find it useful to define entirely new investment packages that combine complementary investments, while one uses multiplicative value functions to measure benefits from those complementary investments. Only one country reports complementarities are ignored, although they explain this is addressed in follow-on processes.

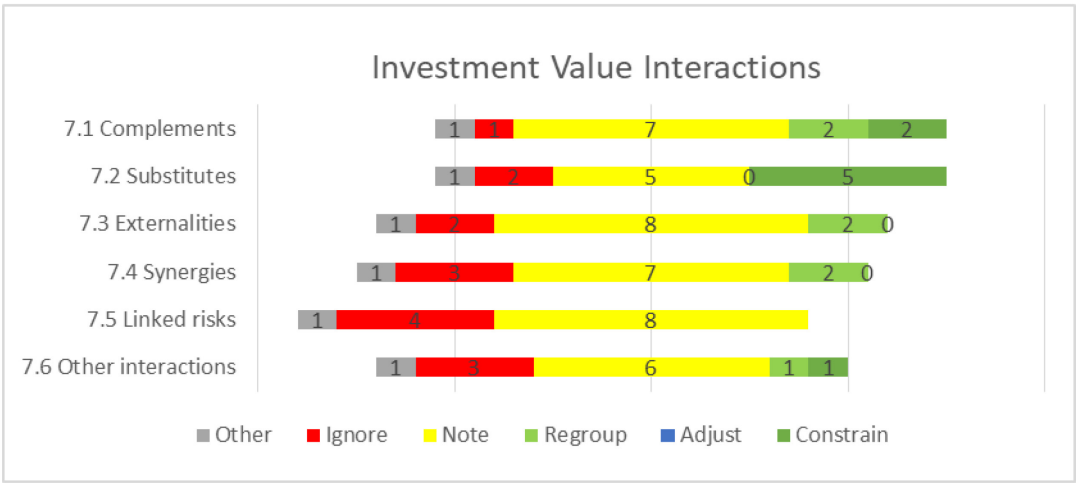



**Figure CA7-1: Alternative Investment Interactions.**

In the case of "*Substitutes*" – where one investment could replace another – nations were equally split between requiring the PIP to only include one of the competing investments (5 countries) and noting potential redundancies, and adjusting the PIP accordingly, without explicitly modelling the effect (5 countries). Two respondents indicate substitutes are ignored in the PIP process but addressed in follow-on processes.

Eight countries recognize portfolio investments that might offer positive "*Externalities*" – spillover benefits that partially satisfy additional PIP requirements other than requirement they were originally designed to

[9] Generally, only one or the other investment is needed in the case of substitutes, unless they offer value in risk reduction – i.e., redundancy in case one fails.

satisfy – but do not explicitly model the effect. Interestingly, two countries create new investment packages for the PIP that consist of combinations of overlapping investments. Another two ignore these interactions leaving them for follow-on processes. Meanwhile, seven nations recognize "*Synergies*" – where two or more investments offer more benefits together than individually – but do not model them explicitly. However, two other countries define new investment packages in the PIP that include combinations of synergistic investments that help determine/model their combined value. Only three countries report they do not consider synergies in the PIP process.

In the case of investments that rely on the same technologies, the same suppliers, the same scarce resources, etc., the same problem can delay or stop several different investments. Eight countries recognize this risk and adjust their PIP accordingly, but do not explicitly model the common risks. Only one country uses decision tree models to explicitly estimate the risks of linked investments. Meanwhile, four other countries that ignore these risks indicate this is addressed in follow-on processes.

Finally, the survey solicited responses as to whether additional interactions and/or other approaches are used by nations to address investment interactions in the PIP process. One nation adds constraints to help focus the PIP process on investment combinations that maximize benefit. Another country develops new investment packages as feasible combinations of existing investments and model properties of these combined packages. Six countries indicate they discuss, but mostly do not explicitly model, other interactions during PIP deliberations, such as industrial base limitations, cost-effectiveness considerations, and the possibility of partially investing in systems.

## CA7.1 Summary

While respondents generally consider investment interactions to be important in the PIP process, they tend not to use formal models or constraints to help address those interactions. In the case of investments that are complements, sequential complements (linked execution), or those that provide positive externalities, a few countries did find it useful to create new investment alternatives that combine those investments. There appears to be consensus among respondents that while investment interactions including potential substitutes are an important issue, it is difficult to capture all the complexities. They appear to be mostly incorporated into the PIP decision process in a discussion-based format (deliberations) that may be supported by prior capability-based planning models and other analyses.

## Appendix C.8: RISK MODELING IN DEFENCE PORTFOLIO PLANNING

Multiple risks exist in building a Planned Investment Portfolio (PIP). This part of the survey explores the extent to which countries recognize and model various risks in their PIP decision process. Risk assessment models in the literature typically address three fundamental questions:

1) What can go wrong?
2) a) What are the chances?; and
   b) What are the consequences/outcomes? [1]

The first step is to identify/describe potential risks. In evaluating investment options for a PIP, there are three main concerns: "*Cost*" – Risk an investment may cost more/less than estimated; "*Schedule*" – Risk an investment might be available earlier/later than expected; and "*Performance*" – Risk an investment delivers more/less value (benefits) than anticipated.

Another important risk in building a PIP involves the "*Budget*" – Risk future funding may be more/less than anticipated. Depending on how funds are allocated (i.e., "colours of money"), budget risks can impact individual investments, and/or the entire portfolio.

At the portfolio level, the two main concerns are: "*Affordability*" – Risk the total costs of the portfolio might end up requiring more funding than future budgets allow; and "*Implementation*" – Risk the portfolio delivers more/less capabilities than anticipated.

Finally, it may be helpful to recognize the risk presented by information uncertainty in the PIP decision process. Some data/information used to guide PIP decisions may be biased or unreliable to mislead decision makers.

Once risks are identified/described, the next step is to estimate their likelihood, and their potential impact (consequences/outcomes). Survey results reported in Figure CA8-1, and in accompanying comments, reveal that while many nations recognize a variety of risks in their PIP decision process, most do not explicitly model those risks, nor assign specific probabilities to assess their likelihood. For example, one nation that recognizes a wide variety of risks explains: *"risk modeling relies on the description of risks, probability of occurrence, impacts (delays, costs, quality), criticality, financial provisions and decisions to mitigate risks … but not as rigorously as the phrasing [of the questions] tends to indicate."* Meanwhile, other nations that did not report a high level of risk modeling nevertheless explain: *"We identify risks, but do not explicitly model them," "We discuss…but do not model,"* or *"We don't tend to model it, but we track where risk is identified."*

Figure CA8-1 indicates "*cost*" risks are considered/modelled by more of our sample nations than "*schedule*" or "*performance*" risks in evaluating individual candidate investments in a PIP. One nation notes: "*In theory, cost risk is explicitly considered at the Analysis of Alternatives phase prior to program initiation. In practice, cost and schedule risk are always underestimated*." Regarding performance modelling, nations comment: "*…performance is generally treated as known with certainty*"; "*A planning assumption is that the candidate investment will fulfil capability requirements*."

Turning from risks associated with (individual) candidate investments in a PIP, to risks involving the entire portfolio, while roughly half of respondents attempt to model future "*budgets*" and "*affordability*," the risks associated with future PIP "*implementation*" (benefits) appear somewhat more challenging to model. In accompanying comments nations report: "*Performance risk management is project management after PIP is accepted, in the PIP implementation stage*"; "Yes we do [address affordability] and adjust within the PIP funding envelope"; and "*An important modelled factor of future PIP budget uncertainty…is GDP [and] the evolution of the geopolitical security environment and its potential impact…*"

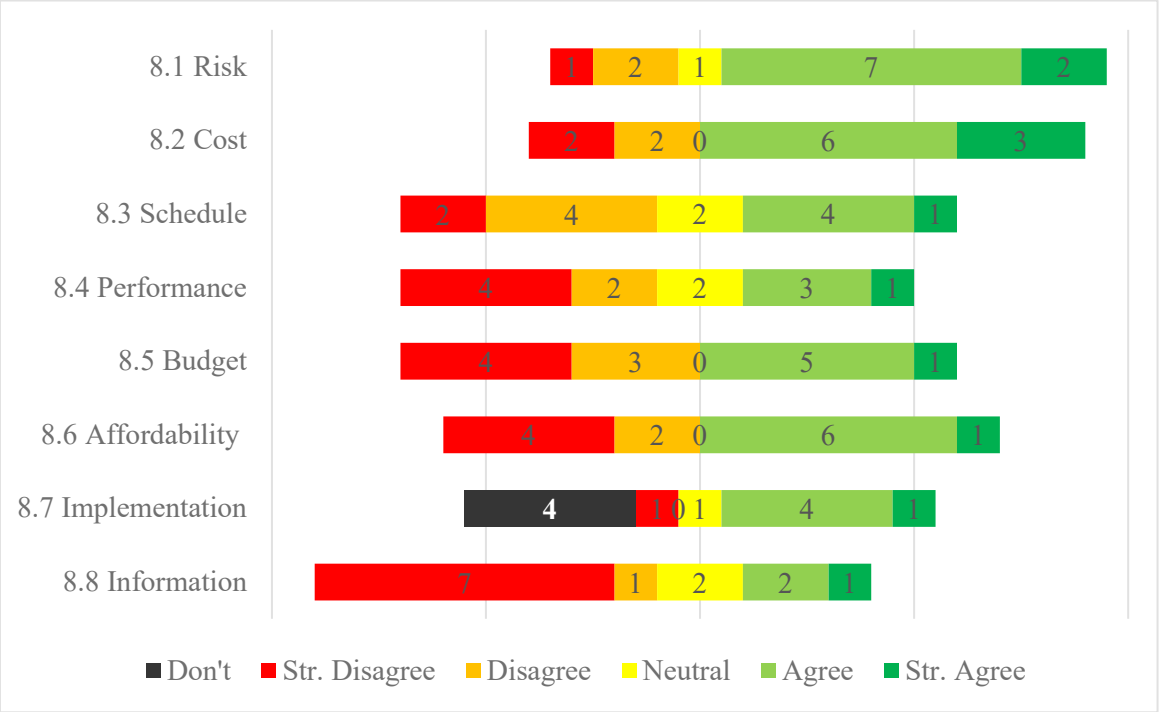



**Figure CA8-1: Risks Modelled by Nations in a Planned Investment Portfolio (PIP).**

Among nations that indicated they do not explicitly model budgets or affordability, the accompanying comments are nevertheless revealing: *"[We] do not model but we have contingency planning"; "Uncertainty about future investment budgets is partially handled by maintaining a candidate list of potential investment projects, that are currently not prioritized in the plan"; "We plan [Budgets] around what the government last indicated it would provide…[and Affordability is conducted] within the [Chief Financial Officer's] staff…"* Finally, while most respondents indicate they do not explicitly model "information" risks (i.e., the accuracy and reliability of data used in PIP decisions), this may be included in other risk assessments.

## CA8.1 Summary

Multiple risks exist in building a PIP. The survey results and accompanying comments reveal that while many nations recognize, describe, and discuss a variety of risks in their PIP decision process, they mostly do not explicitly model those risks, nor assign specific probabilities to assess their likelihood. This may present a good opportunity for nations to incorporate more formal tools and techniques to help assess risks, and ultimately to develop vital risk mitigation strategies.

## CA8.2 References

[1] ISO 31000 (2018) Risk Management – Guidelines.

## Appendix C.9: RESOURCE LIMITATIONS IN PORTFOLIO DECISIONS

This part of the survey explores how nations address several potential resource limitations that could impact the successful deployment and operation of candidate investments in a Planned Investment Portfolio (PIP). Nations face multiple possible limitations as they consider investments in new systems. This part includes thirteen, in an attempt to determine which might rank as most important for nations to consider:

1) **Funding:** availability of financial resources to invest in new systems;
2) **R&D:** capacity and expertise required to conduct any necessary research and development;
3) **Project Management:** capability of individuals with administrative, procurement, and contracting expertise to successfully deliver programs within funding and on schedule;
4) **Facilities:** availability of necessary infrastructure (buildings, airfields, etc.) and ancillary equipment (launch vehicles, etc.) involved in the execution of certain investments (e.g., testing and evaluation);
5) **Execution Services:** necessary services that may only be available periodically or seasonally (e.g., defence construction in colder climates);
6) **Space:** square footage, acreage, or air space, etc. that may be required to successfully operate systems;
7) **Logistics:** transportation required to deliver and move new systems once delivered;
8) **Personnel:** quantity and quality of workforce required for successful operation;
9) **Training:** obtaining different categories of skills/knowledge and equipment (e.g., simulators) to successfully operate a system;
10) **Maintenance:** equipment, and expertise required to support new systems;
11) **Operating Budget:** sufficient funds to operate the system at full capacity;
12) **Engineering:** expertise required to execute mid-life upgrades to systems; and
13) **Divestment:** ability to dispose of, or sell, systems that reach the end of their useful life.

Figure CA9-1 reveals that nations consider many possible limitations in their Planned Investment Portfolio (PIP) decisions. The most common limitations routinely discussed, treated as binding constraints, and/or modelled, are the availability of investment **Funding** (11 respondents) and **Operating Budgets** (10 respondents). Accompanying comments suggest that while defence investment funding often appears as a fixed constraint in portfolio deliberations, it can be subject to periodic negotiations and iterative discussion, and in several cases, is supported by numerical models. Meanwhile, operating budgets also appear to be "taken into account initially in the PIP planning process" while recognizing "challenges [in] managing operating and sustainment costs." Interestingly, every respondent indicated their nation addresses these concerns either inside (majority) or outside (minority) the PIP process.

Other common limitations considered in PIP decisions reported in Figure CA9-1 are **Facilities**, **Project Management**, and **Training** (11, 9, and 8 respondents). The accompanying comments suggest several nations routinely discuss the capacity of ND facilities and training requirements in their PIP process and consider project management crucial for effective planning, and the achievement of expected outcomes.

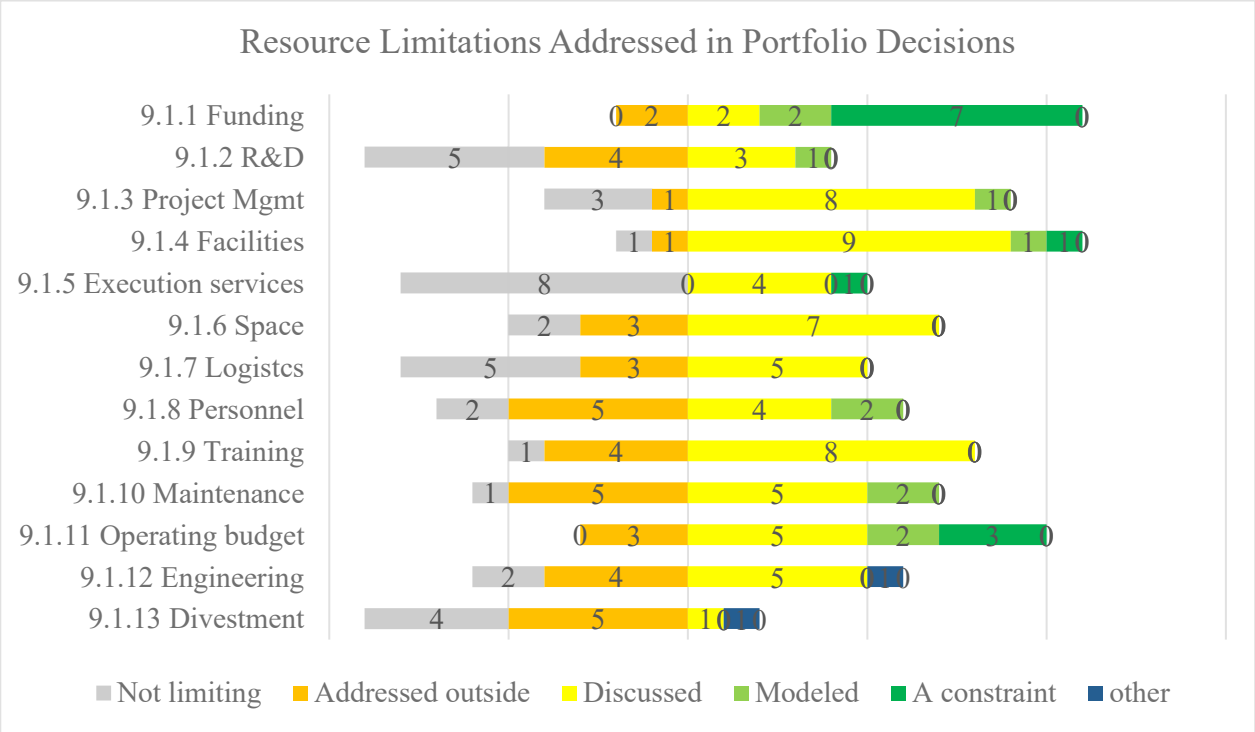



**Figure CA9-1: Possible Resource Limitations Considered in Investment Portfolio Decisions.**

According to Figure CA9-1, the next most common limitations routinely discussed by countries are **Space**, **Maintenance**, and **Personnel** (7, 7, and 6 respondents). The majority of respondents indicate these issues are either discussed within or outside the PIP process, but a few do not consider them limitations.

The accompanying comments indicate that in some countries space considerations are a "routine enabler in discussions for all projects." With respect to maintenance requirements one nation indicates "information is collected per project…within the portfolio planning processes," while another indicates these considerations are not in the PIP process, and instead "part of project and capability planning by the Services who have…industry knowledge."

Reflecting another split, when it comes to consideration of personnel limitations one nation comments these issues are "routinely discussed and often modelled [and] a significant challenge for workforce planners," while another states they are "specific to projects and don't come into portfolio planning processes."

Interestingly, **Logistics**, **Engineering**, and **Execution** concerns are only routinely discussed in portfolio planning in five countries, with several nations not seeing them as significant limitations. It also appears from Figure CA9-1 that R&D and Divestment are minor considerations in the PIP process. Most countries indicate these are either addressed outside the PIP process or not limiting. One nation in the accompanying comments appears to capture a general sentiment regarding the limitation of R&D capability: *"[We] don't tend to invest where the R&D has not already been worked out." Finally, another nation reflects what appears to be commonly acknowledged, that while divestment may be discussed in "certain extreme cases," it is "generally too far in the future to be considered in the portfolio planning process.*"

## CA9.1 Summary

Nations face multiple possible resource limitations as they consider portfolio investments in new systems. The approach adopted by responding nations to address these limitations tends to be more ad hoc and involve

discussions and deliberations, rather than the application of specific constraints or formal modelling. Of the thirteen examples presented in the survey, respondents rank procurement funding and operating costs as the most significant. This was followed by concerns over adequate facilities, project management expertise, and training requirements necessary for the successful deployment and operation of new systems. Sufficient space and maintenance capacity, and personnel with appropriate skills/knowledge also appeared as important considerations. Meanwhile, transportation/logistics requirements, engineering expertise, and periodic/seasonal service issues appeared to be relatively less important. The capacity for research and development appears to be of minor importance largely because it is anticipated it will already be embedded in new systems. Divestment is also a minor consideration as it mostly lies beyond the Planned Investment Portfolio (PIP) horizon. The survey results suggest several resource limitations do appear to be significant and play important roles in many nations' Planned Investment Portfolio (PIP) decisions.

# Annex D – SURVEY QUESTIONNAIRE

# LINKING STRATEGIC INVESTMENT/DIVESTMENT PLANNING TO DEFENCE OUTCOMES: SURVEY OF NATIONAL DEFENCE INVESTMENT PRIORITIZATION

## Introduction

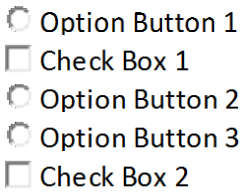
| | |
|---|---|
| **Who is SAS-134:** | We are a 6-nation collaboration under the NATO Science & Technology Organization (Systems Analysis and Studies Panel**)**<br>SAS-134 ***Linking Strategic Investments & Divestments to Defence Outcomes*** (AUS, CAN, CZE, FIN, FRA, USA) |
| **What are we doing:** | We have examined the literature on how to prioritize National Defence (ND) capital investments. Now, we are conducting an unclassified survey of current ND capital investment planning practice, in order to discover, learn and share best practices. |
| **Background:** | Given limited resources and an uncertain future, capital investments for national defence (ND) must be chosen carefully to achieve future security and public confidence. Better plans contribute to better long-term national security. |
| **Aim:** | Identify global best practices for cost-informed ND capital investment prioritization, to share with NATO and partner nations. |
| **Survey Goal:** | Identify how nations prioritize their defence investments, and identify where nations apply best practices from the literature. |
| **Scope:** | All processes by which nations conduct cost-informed prioritization of future major investments in capital equipment (including IT/CIS) and any other strategic resources prioritized at the same time. |
| **Desired Respondents:** | Those involved (preferably in the past 5 years) in making or providing analytical support to cost-informed decisions prioritizing defence capital investments that will deliver, among other things, major capital equipment. |
| **What we ask:** | Please provide as much detail as you can about your ND investment prioritization process and supporting analyses. |
| **Time commitment:** | Respondents who are able to provide all requested information concisely will take approximately 2 hours to complete the survey. |
| **Why complete the survey:** | Besides collecting information, the survey is designed to be thought provoking. We promise the confidentiality and anonymity of all individual respondents and their nations in all reported results.<br>We will provide each respondent with a copy of our annotated bibliography of best National Defence capital investment prioritization practices and a summary of our analysis and findings. |

## Instructions

**Survey focus:** Governments periodically require their National Defence (ND) to state what they plan to buy in the future and what it will cost the government. For example, every NATO member considers the threats they could confront in the future and their alliance responsibilities, in order to identify future capabilities required to defend their nation and support the alliance. The difference between expected defence capabilities (as current investments deliver) and those required generates demand for new investments. Altogether, the cost of these investments often exceeds what the government is willing or able to spend on new defence investment. This survey is about how choices are made to achieve the best available outcomes and close the gap between desired defence spending and funding realities.

**Collaboration:** Where possible, we encourage collaboration in answering the survey between those who have participated in negotiations to draft or revise the list of prioritized ND investments and those who produce the analyses that inform investment decision-making.

**Multiple choice menus:** Each question offers a mix of possible response types.




The response types reflect our understanding of which options are mutually exclusive and which can be logically combined with other options. Please select the options that best reflect your answer. Most questions also offer an "Other" option, with a box for your comments.

**Sensitivity:** Some respondents may consider the requested information too sensitive to provide, or too sensitive for an unclassified survey. The response menus let you indicate this if necessary.

**On paper or electronically:** The survey consists of 105 substantive questions, besides those identifying respondents. It can be completed electronically in Excel or with pencil on a printout of the provided .pdf file. If more paper space is needed than the comment boxes provide in the .pdf, you can create extra comment space in the spreadsheets (see below) and then print them from Excel.

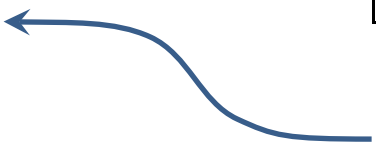
**Electronic format survey:** The electronic survey consists of 7 Excel workbooks containing 11 sheets of survey questions numbered 0 - 10. We recommend having only one workbook open at a time, as Excel-based surveys impose significant burden on computer processor memory.

**Electronic cues:** Whenever you wish to enter information other than a menu selection, you can do so in the cell provided for this. Checking the box beside "I have a comment:" turns the comment cell green:

| | |
|---|---|
| Comment on this topic: | |

After you have entered your text, the text field will return to white:

| | |
|---|---|
| Comment on this topic: | This is my added information… |



If you need more room for your comments, *you can make room* by left-clicking the line to the left of the bottom of the comment cell **here**, and dragging it downward (and then, if completing on paper, reprinting the page).

**Completed Excel files:** Once you have completed the questions in a workbook, please save it with a new name that ends with the original filename and begins with a three-letter abbreviation for your nation. Please return the completed workbooks to:

**Prof. Juha-Matti Lehtonen**
**Email:** Juha-Matti.Lehtonen@mil.fi
**Mailing address:** Department of Military Technology
National Defence University
PO Box 7
FI-00861
Finland

**Paper format survey:** The 105 questions are presented in 67 .pdf pages with the survey sheet names and pages in the footer of each page.

**Non-US paper sizes:** The .pdf and Excel page sizes are set to "Letter" (215.9 mm x 279.4 mm), but their printable content is always narrower than 210mm to ensure they also fit on an A4 page (210mm x 297mm). Survey pages also fit onto a JIS B4 page (257mm x 364mm).

**Completed paper files:** Please return the completed paper survey to Prof. Juha-Matti Lehtonen (see above). It can either be scanned to PDF and FTP'd or else the paper sheets can be mailed to his postal address, above.

Nations differ in the structures and constraints they impose on strategic investment planning, the terminology used to describe their planned investment portfolio (PIP), and the processes used to develop it. This page is intended to establish a common language for this discovery process.

## Glossary

**Alternative portfolio:** A particular combination of candidate investments under consideration to be put forward as a new or updated Planned Investment Portfolio (or PIP) for ND.

**Candidate investment:** A proposed expenditure competing for inclusion in the PIP designed to satisfy, at least in part, one or more National Defence (ND) requirements.

**Consensus model:** A tool that aids negotiation toward consensus by showing the degree and character of stakeholder agreement or disagreement.

**Decision Conferencing (for this survey):** A set of meetings attended by decision makers and all key stakeholders in which a skilled facilitator leads the group through the (re)formulation of a Planned Investment Portfolio.

**Decision tree:** A branching structure representing sequences of mutually exclusive decisions and probabilistic events with their outcomes.

**Dialogue Decision Process:** A sequence of meetings between a team of decision-makers and stakeholders and a team of analysts together executing defined stages in the (re)formulation of a Planned Investment Portfolio.

**National Defence (ND):** The national military forces and the set of government-funded organizations that directly govern or enable them.

**Optimization:** A mathematical (software-assisted) strategy that explores possible investment combinations to find the one that both satisfies constraints and promises the greatest combined benefit.

**Participating stakeholder:** A participant in the investment planning process with an interest in the execution of PIP investments or the outcomes they will achieve.

**PIP criterion: (Plural: PIP criteria)** A desired property, characteristic or feature of the combination of investments in the PIP.

**Planned Investment Portfolio (PIP):** A government-endorsed set of costed and prioritized future investments intended to result in the acquisition of, at least, major capital equipment. The PIP is also defined to include the other types of investment competing with capital equipment investments for the same allocation of investment funding, simultaneously prioritized within the same decision processes.

**Portfolio metric:** A means by which available information is transformed to produce a score showing the degree of presence or absence of a desirable or undesirable property in a portfolio. Metric(s) can measure costs, specific types of investment benefit, budget implications, timings/schedules, risk/uncertainty, etc.

**Requirement:** A specific ND need to be satisfied or problem to be solved, motivating the development of one or more candidate investments involving the planned expenditure of money to acquire goods and services.

**Value function:** An estimated measure of the amount of benefit (value or utility) of some kind expected from specific metric scores or levels .

**We:** Those in the nation of the survey respondent(s) who oversee, execute or provide analytical support for future investment prioritization for ND in their nation. (Note that "We" may not necessarily be the survey respondents.)

## Respondent Contact Information

Name: _____ _____
*Title* *Given name & optional initials* *Family name*

Email: _____

Phone: _____

Nation: _____

Organization: _____

*Clarifying comments (optional)*

Please indicate which role(s) best describe the involvement of the people responding to this survey, and the number of years since they were involved in each role.

| Yrs since last Involvement | Roles of Survey Respondents | Role Descriptions |
|---|---|---|
| | ☐ An Investment Plan approval authority within ND | On the approval chain within ND for any revised capital investment prioritization |
| | ☐ ND investment prioritization process owner | Accountable for ND having a working process to prioritize its capital investments |
| | ☐ Responsible for analytical support to ND Investment Prioritization | Leader of the ND organizational unit that produces the analyses on which ND capital investment choices are based |
| | ☐ Participating stakeholder in ND investment prioritization negotiations | Leader of or delegate representing the interests of a military service or civilian defence organization in investment trade-off deliberations |
| | ☐ ND investment prioritization analyst | Generator of decision support products enabling cost-informed capital investment prioritization decisions |
| | ☐ ND Investment prioritization scientist | Advisor to ND on cost-informed prioritization of capital investments including those delivering equipment |
| | ☐ Other: | Having a role in cost-informed investment prioritization different from the above |

## Part 0 – NATIONAL PIP FEATURES

0.1 Please select the statement below that best describes your ND's use of portfolios of planned investments that must deliver capital equipment (among other things) within a budget.

- ○ My nation's ND develops and updates one or more portfolios of costed and prioritized future capital investments.
- ○ My nation's ND does not develop or update any portfolios of costed and prioritized future capital investments.
- ○ Neither of the above statements accurately describes the way my ND makes plans to acquire capital equipment.
- ☐ I have a comment (on either the question or the answer):

| Comment on my ND having a PIP: |
|---|

If your nation's ND does not use planned investment portfolios:

You have completed your task. Please return the now-complete survey to the survey administrator. Thank you for responding.

If your nation's ND does use budget-constrained planned investment portfolio's:

Please continue with the rest of the survey.

0.2 Investment needs of the following ND organizations are addressed within the Planned Investment Portfolio (PIP):

- ○ All National Defence and support organizations (Navy, Army, Air Force, regional commands, Joint staff, Defence Procurement, etc.)
- ○ All ND organizations except those listed below (List the organisations not served by the PIP):
- ○ No ND organizations except those listed below: (List the organisations that are served by the PIP)
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment (on either the question or the answer):

| Comments on ND Organizations served by PIP investments: |
|---|
| ND Org's served by PIP - exception (1): |
| ND Org's served by PIP - exception (2): |
| ND Org's served by PIP - exception (3): |
| ND Org's served by PIP - exception (4): |
| ND Org's served by PIP - exception (5): |
| ND Org's served by PIP - exception (6): |
| ND Org's served by PIP - exception (7): |
| ND Org's served by PIP - exception (8): |
| ND Org's served by PIP - exception (9): |
| ND Org's served by PIP - exception (10): |
| ND Org's served by PIP - exception (11): |
| ND Org's served by PIP - all other exceptions: |

0.3 The following sets of capabilities are maintained and renewed through the investments in the PIP:

- ○ All ND capabilities (Command & Control, Strategic Lift, Strategic Deterrence, Major weapon systems, Special Forces, Logistics, Defence Management, etc.)
- ○ All ND capabilities except those listed below: (List the capability sets not renewed in the PIP)
- ○ No ND capabilities except those listed below: (List the capability sets that are renewed in the PIP)
- ○ Information sensitivity prevents me from answering.
- ○ I would describe them in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment (on either the question or the answer):

| |
|---|
| **Comments** on ND capability sets served by PIP investments: |
| Capab'y sets renewed in PIP - exception (1): |
| Capab'y sets renewed in PIP - exception (2): |
| Capab'y sets renewed in PIP - exception (3): |
| Capab'y sets renewed in PIP - exception (4): |
| Capab'y sets renewed in PIP - exception (5): |
| Capab'y sets renewed in PIP - exception (6): |
| Capab'y sets renewed in PIP - exception (7): |
| Capab'y sets renewed in PIP - exception (8): |
| Capab'y sets renewed in PIP - exception (9): |
| Capab'y sets renewed in PIP - exception (10): |
| Capab'y sets renewed in PIP - exception (11): |
| Capab'y sets renewed in PIP - other excep'ns: |

0.4 Our PIP includes the following types of investments:

- ○ All investment types (Research & Development, Capital Equipment, Defence Construction, Military Personnel, Civilian Personnel, Training, etc.)
- ○ All investment types except those listed below: (List the budget categories not included in the PIP)
- ○ No investment types except those listed below: (List the budget categories that are included in the PIP)
- ○ Information sensitivity prevents me from describing them.
- ○ I would describe them in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment (on either the question or the answer):

| |
|---|
| Comment on ND Capabilities served by PIP investments: |
| Investment types in the PIP - exception (1): |
| Investment types in the PIP - exception (2): |
| Investment types in the PIP - exception (3): |
| Investment types in the PIP - exception (4): |
| Investment types in the PIP - exception (5): |
| Investment types in the PIP - exception (6): |
| Investment types in the PIP - exception (7): |
| Investment types in the PIP - exception (8): |
| Investment types in the PIP - exception (9): |
| Investment types in PIP - exception (10): |
| Investment types in PIP - exception (11): |
| Investment types in PIP - other exceptions: |

0.5 The decision process that prioritizes future acquisitions of ND capital equipment (including information systems) also prioritizes *other* planned resource allocations (or reallocations) of the following types: (Please check all applicable boxes.)

- ○ I can answer this question.
- ☐ Major upgrades to capital equipment already in service
- ☐ Acquisition of lands for ND use
- ☐ Major modifications to existing ND facilities (for renovation or re-purposing)
- ☐ Construction of new facilities for ND use
- ☐ Acquisition of software for ND-wide use
- ☐ Disinvestment (cancellation of ND investments already underway)
- ☐ Divestment (liquidation and disposal of current ND assets)
- ☐ Changes to the size of the professional military
- ☐ Changes to the size of the reserve military
- ☐ Changes to the size of the conscript force
- ☐ Other strategic investments not listed above (list up to six additional types below):
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment (on either the question or the answer):

| |
|---|
| Comment on other resource allocations planned with PIP: |
| Other resource allocations prioritized (1): |
| Other resource allocations prioritized (2): |
| Other resource allocations prioritized (3): |
| Other resource allocations prioritized (4): |
| Other resource allocations prioritized (5): |
| Other resource allocations prioritized (6): |

0.6 The PIP typically or usually undergoes a fundamental review or reset:

- ○ Every year.
- ○ Every 2 years.
- ○ Every 3 years.
- ○ Every 4 years.
- ○ Every 5 years.
- ○ Less often than every 5 years.
- ○ When the government changes.
- ○ Whenever the government directs.
- ○ On a different basis than those listed. (Please comment below.)
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment (on either the question or the answer):

| Comment on normal PIP reset: |
|---|

0.7 The length of time (plan length in years) spanned by this PIP is:

| | | | | |
|---|---|---|---|---|
| ○ 1 yr | ○ 6 yrs | ○ 11 yrs | ○ 16 yrs | ○ 21 yrs |
| ○ 2 yrs | ○ 7 yrs | ○ 12 yrs | ○ 17 yrs | ○ 22 yrs |
| ○ 3 yrs | ○ 8 yrs | ○ 13 yrs | ○ 18 yrs | ○ 23 yrs |
| ○ 4 yrs | ○ 9 yrs | ○ 14 yrs | ○ 19 yrs | ○ 24 yrs |
| ○ 5 yrs | ○ 10 yrs | ○ 15 yrs | ○ 20 yrs | ○ 25 yrs or more |

- ○ Information that sensitivity prevents me from providing.
- ○ Information I would give in a classified survey, but not here.
- ○ Information I do not have.
- ○ Other (Please comment below.)
- ☐ I have a comment (on either the question or the answer):

| Comment on length of the PIP: |
|---|

0.8 The number of sub-periods into which this PIP plan length is divided is:

- ○ 1 sub-period
- ○ 2 sub-periods
- ○ 3 sub-periods
- ○ 4 sub-periods
- ○ 5 sub-periods
- ○ 6 sub-periods
- ○ 7 sub-periods
- ○ 8 sub-periods
- ○ 9 sub-periods
- ○ 10 or more sub-periods
- ○ Information sensitivity prevents me from providing.
- ○ Information I could give in a classified survey, but not here.
- ○ Information I do not have.
- ○ Other (Please comment below.)
- ☐ I have a comment (on either the question or the answer):

| Comment on number of PIP sub-periods: |
|---|

0.9 The lengths of the sub-periods into which this PIP is divided, and the main features distinguishing each sub-period are:

- ○ Information I can provide below:
- ○ Information sensitivity prevents me from providing.
- ○ Information I could give in a classified survey, but not here.
- ○ Information I do not have.
- ○ Other (Please comment below.)
- ☐ I have a comment (on either the question or the answer):

| | |
|---|---|
| Comment on PIP sub-period lengths: | |
| | |
| Years in 1st sub-period: | Features of 1st sub-period: |
| Years in 2nd sub-period: | Features of 2nd sub-period: |
| Years in 3rd sub-period: | Features of 3rd sub-period: |
| Years in 4th sub-period: | Features of 4th sub-period: |
| Years in 5th sub-period: | Features of 5th sub-period: |
| Years in 6th sub-period: | Features of 6th sub-period: |
| Years in 7th sub-period: | Features of 7th sub-period: |
| Years in 8th sub-period: | Features of 8th sub-period: |
| Years in 9th sub-period: | Features of 9th sub-period: |
| Years in 10th sub-period: | Features of 10th sub-period: |

0.10 Please describe briefly the stages in the process by which a new PIP is developed within ND. (Up to 12 stages can be described.)

- ○ I can give this information below:
- ○ Information sensitivity prevents me from answering.
- ○ I would describe them in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment (on either the question or the answer):

| |
|---|
| Comment on normal PIP drafting stages: |
| 1st drafting stage: |
| 2nd drafting stage: |
| 3rd drafting stage: |
| 4th drafting stage: |
| 5th drafting stage: |
| 6th drafting stage: |
| 7th drafting stage: |
| 8th drafting stage: |
| 9th drafting stage: |
| 10th drafting stage: |
| 11th drafting stage: |
| 12th drafting stage: |

0.11 Please briefly describe the stages in the process by which a newly drafted (or redrafted) PIP within ND is finalized and accepted by the government. (Up to 12 stages can be described.)

- ○ I can give this information below:
- ○ Information sensitivity prevents me from answering.
- ○ I would describe them in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment (on either the question or the answer):

| |
|---|
| Comment on normal PIP finalization stages: |
| 1st finalizing stage: |
| 2nd finalizing stage: |
| 3rd finalizing stage: |
| 4th finalizing stage: |
| 5th finalizing stage: |
| 6th finalizing stage: |
| 7th finalizing stage: |
| 8th finalizing stage: |
| 9th finalizing stage: |
| 10th finalizing stage: |
| 11th finalizing stage: |
| 12th finalizing stage: |

## Part 1 – INCLUDING STAKEHOLDERS

1.1 How many decision-makers within ND exercise the authority to approve the PIP within ND?

- ○ A single decision maker (Please describe below.)
- ○ A decision making body of 2 (Please describe below.)
- ○ A decision making body of 3 (Please describe below.)
- ○ A decision making body of 4 (Please describe below.)
- ○ A decision making body of more than 4 (Please describe below.)
- ○ Information sensitivity prevents me from answering.
- ○ I would describe them in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment on this question:

| |
|---|
| Our decision-maker(s): |
| Comment on number of decision makers: |

1.2 We use the following methods / tools to address conflicting objectives and judgements among decision-makers & stakeholders toward building consensus:

- ○ I can answer this question.
- ☐ Consensus modelling
- ☐ Decision Conferencing
- ☐ Dialogue Decision Process
- ☐ Methods not listed above, including the following (up to 3):
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment:

| |
|---|
| Comments on consensus building tools: |
| Other tool (1) for differing perspectives: |
| Other tool (2) for differing perspectives: |
| Other tool (3) for differing perspectives: |

1.2.1 Our Decision Conferencing incorporates the following features:

- ○ We do not use Decision Conferencing.
- ○ I can answer this question.
- ☐ Professional facilitation.
- ☐ Facilitated development of portfolio value criteria, value modelling and calibration.
- ☐ Continual display of developed results (judgements made, models developed, portfolio scores & values)
- ☐ May be attended by government officials from outside of ND.
- ☐ May be attended by members of the national body that makes law.
- ☐ May be observed by cleared persons with no role in PIP development or government acceptance.
- ☐ Other features of our Decision Conferencing (list up to 3 more):
- ○ Information sensitivity prevents me from answering.
- ○ I would describe them in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment on our use of Decision Conferencing:

| |
|---|
| Comments on our Decision Conferencing: |
| Other features of our Decision Conferencing 1: |
| Other features of our Decision Conferencing 2: |
| Other features of our Decision Conferencing 3: |

1.2.2 Our Dialogue Decision Process (DDP) incorporates the following features:

- ○ We do not use a Dialogue Decision Process.
- ○ I can answer this question.
- ☐ Decision team and analysis team membership is stable throughout the process.
- ☐ The roles played by both the decision and analysis teams are predefined for each stage of the decision process.
- ☐ Decision team and analysis team members are each trained in the role their team plays in each decision stage.
- ☐ The PIP development process follows a standard decision model used across ND for strategic decision making.
- ☐ Other features of our dialog decision process (list up to 3 more):
- ○ Information sensitivity prevents me from answering.
- ○ I would describe them in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment on our use of Dialogue Decision Process:

| |
|---|
| Comments on our use of DDP: |
| Other features of our DDP 1: |
| Other features of our DDP 2: |
| Other features of our DDP 3: |

1.3

Stakeholder preference data collected during PIP development is stored for future reference.

- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would respond in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| Comment on collected data availability: |

1.3.1 Preference data collected from stakeholders during PIP development is available to all participating stakeholders while the PIP is undergoing government approval.

- ○ Stakeholder preference data elicited during PIP development is not stored.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on collected data availability: |
|---|

1.3.2 The stakeholder data elicited during PIP development is available to participating stakeholders after the PIP has undergone government approval.

- ○ Stakeholder preference data elicited during PIP development is not stored
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on collected data availability: |
|---|

## Part 2 – FRAMING THE DECISION

2.1 We ask decision makers and participating stakeholders for their preferences, priorities and what they consider important for the PIP at the start of PIP development or revision.

- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on<br>Values & Priorities<br>Elicitation: |
|---|

2.2 From decision maker and stakeholder preferences, priorities and values, we develop a set of criteria to evaluate the merit of the combined investments in the PIP.

- ○ We don't ask for values and priorities at the start of PIP development.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on<br>criteria for PIP to<br>satisfy: |
|---|

## Part 3 – CHARACTERIZING PIP BENEFIT

2.2.1 The set of developed PIP criteria take the form of ND end-state objectives that PIP execution is to achieve.

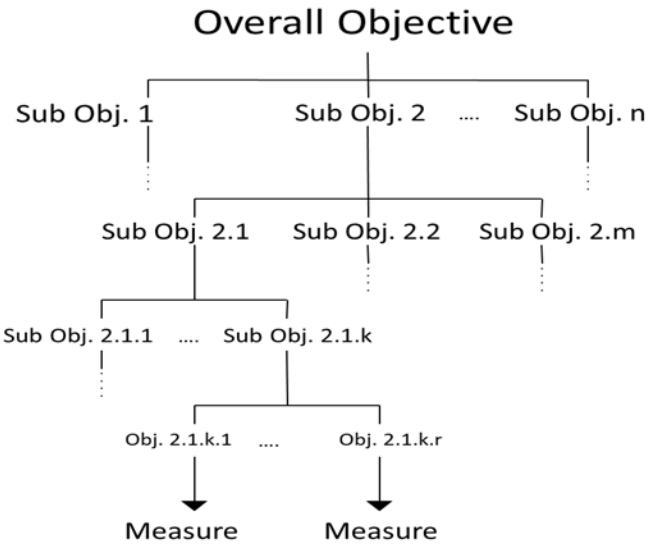
- ○ We do not develop a set of PIP criteria
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on PIP end-state objectives: |
|---|

2.2.1.1 The set of PIP end-state objectives we develop are collectively exhaustive. They include every outcome over which one investment might be chosen over another.

- ○ We do not define end-state objectives for the PIP.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on PIP objective collective exhaustivity: |
|---|




2.2.1.2 We decompose PIP endstate objectives hierarchically into component sub-objectives. (See figure above.)

- ○ We do not define end-state objectives for the PIP.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| Comment on decomposing PIP objectives hierarchically: |

2.2.2 The PIP criteria we develop on a given level are designed to not overlap each other. They are as mutually exclusive or as mutually independent as possible.

- ○ We do not develop a set of criteria for the PIP to satisfy.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on PIP criteria mutual exclusivity: |
|---|

2.2.3 We identify causal relationships between PIP sub-objectives on different branches, where meeting one can be expected to help meet another on a different branch.

- ○ We do not define a hierarchy of PIP sub-objectives.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on identifying causal links between PIP criteria: |
|---|

2.3 We develop portfolio metrics to help distinguish the comparative benefits and costs of alternative investment portfolios.

- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on<br>developing metrics<br>that distinguish<br>PIP qualities: |
|---|

2.3.1 Our portfolio benefit metrics are anchored to PIP criteria. They produce scores that distinguish the degree to which alternative PIPs satisfy specific criteria (at the lowest level, if decomposed hierarchically).

- ○ We do not define criteria for the PIP to satisfy.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on PIP<br>metrics anchored<br>to end-state<br>objectives: |
|---|

3.1 We develop and use metrics that indicate the extent to which a candidate portfolio satisfies criteria set for the PIP.

- ○ We do not develop criteria for the PIP to satisfy.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on metrics indicating criteria satisfaction: |
|---|

3.2 We develop value functions that translate metric scores into amounts of specific types of benefit (value or utility) promised by PIP execution.

- ○ We do not develop metrics to measure satisfaction of PIP criteria.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on translating metric levels into benefit: |
|---|

3.3 We model the overall benefit promised by candidate portfolios as a weighted sum of the specific types of benefit they promise.

- ○ We do not use metrics to measure satisfaction of PIP criteria.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on combining benefit type measures: |
|---|

3.4 We ask decision makers and participating stakeholders to make judgments regarding the relative importance of different types of benefit promised by PIP execution.

- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on eliciting relative importance of benefit types: |
|---|

3.5 We estimate the degree of uncertainty associated with levels of satisfaction of PIP criteria in candidate portfolios.

- ○ We do not model PIP satisfaction of criteria.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on<br>uncertainty<br>estimation in PIP<br>benefits: |
|---|

## Part 4 – MODELLING PIP BENEFIT

4.1 In the following questions, please select the answer best describing **the impact of the following methods on the way you model the benefit expected** from executing the investments in your nation's PIP.

4.1.1 Decision Analysis / Value Focused Thinking

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on use of Decision Analysis: |
|---|

4.1.2 Multi-Attribute Value Theory (MAVT)

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on use of MAVT: |
|---|

4.1 In the following questions, please select the answer best describing **the impact of the following methods on the way you model the benefit expected** from executing the investments in your nation's PIP.

4.1.3 Swing weights

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on use of Swing Weights: |
|---|

4.1.4 Multi-Objective / Multi-Criteria Decision Analysis / Decision Making (MODA / MCDA / MCDM)

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on use of MODA / MCDA / MCDM: |
|---|

4.1 In the following questions, please select the answer best describing **the impact of the following methods on the way you model the benefit expected** from executing the investments in your nation's PIP.

4.1.5 Priority-ranked tiers or lists

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on use of Priority Ranking: |
|---|

4.1.6 Linear additive value models

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on use of linear additive value models: |
|---|

4.1 In the following questions, please select the answer best describing **the impact of the following methods on the way you model the benefit expected** from executing the investments in your nation's PIP.

4.1.7 Multiplicative value models

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on use of multiplicative value models: |
|---|

4.1.8 Outranking methods from the Decision Aid school such as ELECTRE, PROMETHEE, VIKOR and MACBETH

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on use of Outranking methods: |
|---|

4.1 In the following questions, please select the answer best describing **the impact of the following methods on the way you model the benefit expected** from executing the investments in your nation's PIP.

4.1.9 Multi-Attribute Utility Theory (MAUT)

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

Comments on
use of MAUT:

4.1.10 Prospect theory

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

Comments on
use of Prospect
Theory:

4.1 In the following questions, please select the answer best describing **the impact of the following methods on the way you model the benefit expected** from executing the investments in your nation's PIP.

4.1.11 Analytic Hierarchy Process / Analytic Network Process

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| Comments on<br>use of AHP/ANP: |

4.1.12 Tornado diagrams

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| Comments on<br>use of Tornado<br>Diagrams: |

4.1 In the following questions, please select the answer best describing **the impact of the following methods on the way you model the benefit expected** from executing the investments in your nation's PIP.

4.1.13 Influence diagrams

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on use of Influence Diagrams: |
|---|

4.1.14 Decision Trees

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on use of Decision Trees: |
|---|

4.1 In the following questions, please select the answer best describing **the impact of the following methods on the way you model the benefit expected** from executing the investments in your nation's PIP.

4.1.15 Requirements Management

- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| Comments on<br>Ranking<br>Investments: |

4.1.16 Multiple Criteria Optimization (eg. Goal programming, pareto optimization)

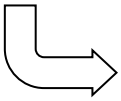
- ○ We do not model the benefit expected from executing the PIP.
- ○ I am not familiar with this technical approach.
- ○ This is unrelated to our modelling of PIP promised benefit.
- ○ This is indirectly related to part of our PIP benefit modelling.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| Comments on<br>use of Multiple<br>Criteria<br>Optimization: |

4.1 In the following questions, please select the answer best describing **the impact of the following methods on the way you model the benefit expected** from executing the investments in your nation's PIP.

4.1.17

We model benefits differently:



- ○ This is indirectly related to the way we model PIP benefit.
- ○ This is directly related to the way we model PIP benefit.
- ○ We use this to model PIP benefit.

- ○ We do not model PIP benefit outside of methods listed above.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ☐ I have a comment:

| |
|---|
| Comments on other relevant methods: |

## Part 5 – CHARACTERIZING COSTS

5.1 **Nations differ in** the cost categories they require their capital investment budgets to cover, and in how they treat investment costs. **Please indicate whether or not each of the following cost components (over the useful life of the investment deliverable) come out of a PIP budget and, if so, how those costs are represented. Please check all applicable boxes.**

**By "Commonly", we mean that 10% or more of candidate investments will treat included costs in the described manner.**

5.1.1 **Cost of Purchase, set-up and integration into the force**

- ○ This is a cost against the PIP budget.
- ○ This is not a cost against the PIP budget.
- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on Cost of Purchase, set-up and integration into the force: | |
|---|---|

5.1.2 **Research & development costs**

- ○ This is a cost against the PIP budget.
- ○ This is not a cost against the PIP budget.
- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on Research & development costs: | |
|---|---|

5.1 **Nations differ in** the cost categories they require their capital investment budgets to cover, and in how they treat investment costs. **Please indicate whether or not each of the following cost components (over the useful life of the investment deliverable) come out of a PIP budget and, if so, how those costs are represented. Please check all applicable boxes.**

**By "Commonly", we mean that 10% or more of candidate investments will treat included costs in the described manner.**

5.1.3 **Project management costs to execute**

- ○ This is a cost against the PIP budget.
- ○ This is not a cost against the PIP budget.
- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on Project management costs to execute: | |
|---|---|

5.1.4 **Costs of real property to support deliverables**

- ○ This is a cost against the PIP budget.
- ○ This is not a cost against the PIP budget.
- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on Costs of real property to support deliverables: | |
|---|---|

5.1 **Nations differ in** the cost categories they require their capital investment budgets to cover, and in how they treat investment costs. **Please indicate whether or not each of the following cost components (over the useful life of the investment deliverable) come out of a PIP budget and, if so, how those costs are represented. Please check all applicable boxes.**

**By "Commonly", we mean that 10% or more of candidate investments will treat included costs in the described manner.**

5.1.5 **Costs of Information Systems to support the deliverables**

- ○ This is a cost against the PIP budget.
- ○ This is not a cost against the PIP budget.
- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| Comment on Costs of Information Systems to support the deliverables: |

5.1.6 **Transition costs (new tactics & training devel't. & delivery, facilities conversion)**

- ○ This is a cost against the PIP budget.
- ○ This is not a cost against the PIP budget.
- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| Comment on Transition costs (new tactics & training devel't. & delivery, facilities conversion): |

5.1 **Nations differ in** the cost categories they require their capital investment budgets to cover, and in how they treat investment costs. **Please indicate whether or not each of the following cost components (over the useful life of the investment deliverable) come out of a PIP budget and, if so, how those costs are represented. Please check all applicable boxes.**

**By "Commonly", we mean that 10% or more of candidate investments will treat included costs in the described manner.**

5.1.7 **Expected annual operating costs (maintenance, repair and consumables)**

- ○ This is a cost against the PIP budget.
- ○ This is not a cost against the PIP budget.
- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on Expected annual operating costs (maintenance, repair and consumables): | |
|---|---|

5.1.8 **Logistic costs to transport investment deliverables and their provisions**

- ○ This is a cost against the PIP budget.
- ○ This is not a cost against the PIP budget.
- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on Logistic costs to transport investment deliverables and their provisions: | |
|---|---|

5.1 **Nations differ in** the cost categories they require their capital investment budgets to cover, and in how they treat investment costs. **Please indicate whether or not each of the following cost components (over the useful life of the investment deliverable) come out of a PIP budget and, if so, how those costs are represented. Please check all applicable boxes.**

**By "Commonly", we mean that 10% or more of candidate investments will treat included costs in the described manner.**

5.1.9 **Costs to train personnel to operate deliverables**

- ○ This is a cost against the PIP budget.
- ○ This is not a cost against the PIP budget.
- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on Costs to train personnel to operate deliverables: | |
|---|---|

5.1.10 **Costs of personnel to operate deliverables**

- ○ This is a cost against the PIP budget.
- ○ This is not a cost against the PIP budget.
- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on Costs of personnel to operate deliverables: | |
|---|---|

5.1 **Nations differ in** the cost categories they require their capital investment budgets to cover, and in how they treat investment costs. **Please indicate whether or not each of the following cost components (over the useful life of the investment deliverable) come out of a PIP budget and, if so, how those costs are represented. Please check all applicable boxes.**

**By "Commonly", we mean that 10% or more of candidate investments will treat included costs in the described manner.**

5.1.11 **Expected costs of mid-life upgrades**

- ○ This is a cost against the PIP budget.
- ○ This is not a cost against the PIP budget.
- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| Comment on Expected costs of mid-life upgrades: |

5.1.12 **Expected end-of-life costs and/or any value recovered**

- ○ This is a cost against the PIP budget.
- ○ This is not a cost against the PIP budget.
- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| Comment on Expected end-of-life costs and/or any value recovered: |

5.1 **Nations differ in** the cost categories they require their capital investment budgets to cover, and in how they treat investment costs. **Please indicate whether or not each of the following cost components (over the useful life of the investment deliverable) come out of a PIP budget and, if so, how those costs are represented. Please check all applicable boxes.**

**By "Commonly", we mean that 10% or more of candidate investments will treat included costs in the described manner.**

5.1.13 **Other cost1**

We charge another cost type against the PIP budget:

- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Besides those listed above, we charge no other cost types against the PIP budget.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

Comment on Other cost1:

5.1.14 **Other cost2**

We charge another cost type against the PIP budget:

- ☐ This cost is commonly estimated as a single number.
- ☐ This cost is commonly estimated as a range of numbers.
- ○ Besides those listed above, we charge no other cost types against the PIP budget.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

Comment on Other cost2:

## Part 6 – MAXIMISING VALUE

6.1 We examine the potential contributions from all candidate investments to each PIP benefit criterion defined.

- ○ We do not define PIP criteria.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on identifying strength of contribution to PIP benefit: |
|---|

6.2 We identify those PIP benefit criteria to which few candidate investments could contribute, constituting a potential benefit gap in the PIP.

- ○ We do not define PIP criteria.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on identifying possible PIP benefit gaps: |
|---|

6.3 We identify potential new candidate investments that would contribute to under-served PIP benefit criteria if funded, reducing the likelihood of PIP execution leaving a benefit gap.

- ○ We don't identify potential benefit gaps in the PIP.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on generating new candidate investments to fill possible benefit gaps: |
|---|

6.4 We use Optimization methods to find the combination of candidate investments promising greatest combined benefit within resource constraints.

- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment
- ☐ I have a comment:

| Comment on use of Portfolio Optimization: |
|---|
| |

6.5 We employ a real options approach, initially prioritizing a combination of investments that exceed the PIP budget (over-programming) and delaying / cancelling investments to satisfy constraints as conditions, risks and opportunities materialize.

- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment
- ☐ I have a comment:

| Comments on use of a Real Options approach: |
|---|

## Part 7 – INVESTMENT INTERACTIONS

7. **For the investment interactions listed in each of the following questions, please select the answers that best represent the way your ND decision process treats them.**

7.1 Candidate investments that will not deliver full benefit without the execution of other enabling investments:

- ○ We constrain enabling investments to accompany prioritized investments in the PIP and exclude from the PIP investments that only enable excluded investments.
- ○ We add value penalties to modelled PIP benefit when enabling and dependent investments are not both selected.
- ○ We define new investment packages as acceptable combinations of interdependent candidate investments and model their benefit accordingly.
- ☐ We use decision trees to model investment benefits with and without enabling investment value.
- ☐ We model the impact of enabling investment risk on enabled investment risk.
- ☐ We use multiplicative value functions to model the benefits to the PIP of enabled and enabling investments with and without each other.
- ○ We note these dependencies in PIP deliberations and adjust the PIP accordingly without modelling the effect.
- ○ We ignore these interactions during PIP development and address them in follow-on processes.
- ○ Information sensitivity prevents me from answering this question.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on investment dependency modelling: |
|---|

7. **For the investment interactions listed in each of the following questions, please select the answers that best represent the way your ND decision process treats them.**

7.2 Candidate investments representing alternative ways to satisfy the same requirement (potentially redundant):

- ○ We constrain the PIP to include only one of the alternative solutions per requirement.
- ○ We model the marginal benefit of redundant investments.
- ○ We define new candidate investments as combinations of redundant investments and model their combined promised benefits.
- ☐ We use decision trees to model the reduced value of combined potentially redundant investment.
- ☐ We model the risks mitigated by potentially redundant investments.
- ☐ We use multiplicative value functions to model the value interactions between redundant investments.
- ○ We note the reduncancy in discussions and adjust the PIP accordingly without modelling the effect.
- ○ We ignore these interactions during PIP development and address them in follow-on processes.
- ○ Information sensitivity prevents me from answering this question.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| Comments on redundant project modelling: |

7. **For the investment interactions listed in each of the following questions, please select the answers that best represent the way your ND decision process treats them.**

7.3 Investment options that also partially satisfy requirements other than the requirement they were designed to satisfy (partially substitutable or overlapping investments):

- ○ We model a penalty to PIP benefit when investments that will deliver overlapping capabilities are selected.
- ○ We create new investments defined as combinations of overlapping capability investments and model their promised benefit.
- ☐ We use decision trees to model investment value added to meet related requirements for overlapping capabilities.
- ☐ We model the risks mitigated by investments that will deliver overlapping capabilities.
- ☐ We use multiplicative value functions to model the value of subsets of the full requirement solution.
- ○ We note investment overlap in deliberations and adjust the PIP accordingly without modelling the effect.
- ○ We ignore these interactions during PIP development and address them in follow-on processes.
- ○ Information sensitivity prevents me from answering this question.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on modelling investments in overlapping capabilities: |
|---|

7. **For the investment interactions listed in each of the following questions, please select the answers that best represent the way your ND decision process treats them.**

7.4 Synergistic candidate investments (generating more value together than the sum of their parts):

- ○ We constrain the PIP to include all candidate investments that synergize with prioritized investments.
- ○ We model added premiums to PIP value when synergistic investments are selected.
- ○ We define new investment packages as combinations of the synergistic investments and model their combined value.
- ☐ We use decision trees to model the increased value of combined synergistic investments.
- ☐ We use decision trees to model the risk associated with synergistic investments.
- ☐ We use multiplicative value functions to model the value of synergistic investments in combination.
- ○ We note the synergy in deliberations and adjust the PIP accordingly without modelling the effect.
- ○ We ignore synergies during PIP development and address them in follow-on processes.
- ○ Information sensitivity prevents me from answering this question.
- ○ I would answer in a classified survey but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on investment synergy modelling: |
|---|

7.5 Investment options that face linked execution risks:

- ○ We use decision trees to model the joint probability of linked investment risks.
- ○ We note the risk linkages in deliberations and adjust the PIP accordingly without modelling their joint risk.
- ○ We ignore linked risks during PIP development and address them in follow-on processes.
- ○ Information sensitivity prevents me from answering this question.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comments on linked investment risk modelling: |
|---|

7. **For the investment interactions listed in each of the following questions, please select the answers that best represent the way your ND decision process treats them.**

7.6

- ○ We model additional interactions:
  - ○ We constrain the PIP to include investment combinations that maximize benefit.
  - ○ We model the interactions by adding premiums or penalties.
  - ○ We define new investment packages as feasible combinations of the interacting original investments and model their properties in combination.
  - ○ We use decision trees to analyse significant property interactions.
  - ○ We note the interacting option properties in deliberations and adjust the PIP accordingly without modelling the interaction.
  - ○ Other (Please comment below.)
- ○ We recognize no investment interactions other than those previously listed.
- ○ Information sensitivity prevents me from answering this question.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment:

| Comments on additional investment interactions: |
|---|

## Part 8 – ADDRESSING RISK AND UNCERTAINTY

8.1 We model risk associated with the PIP.

- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment.

| Comment on modelling PIP risks: |
|---|

8.2 We model the cost risk for each candidate investment.

- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment.

| Comment on modelling PIP investment cost risk: |
|---|

8.2.1 Our cost risk modelling for candidate investments links specific outcomes to specific probabilities.

- ○ We do not model candidate investment cost risk.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment.

| Comment on linking cost outcomes & probabilities: |
|---|

8.3 We model the schedule risk for each candidate investment.

- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from giving this information.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on modelling PIP investment schedule risk: |
|---|

8.3.1 Our schedule risk modelling for each candidate investment links specific outcomes to specific probabilities.

- ○ We do not model candidate investment schedule risk.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on linking schedule outcomes & probabilities: |
|---|

8.4 We model the performance risk for each candidate investment.

- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment

| Comment on modelling PIP investment performance risk: |
|---|

8.4.1 Our performance risk modelling links specific outcomes to specific probabilities.

- ○ We do not model candidate investment performance risk.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey but not here
- ○ I don't have that information
- ○ Other (Please comment below.)
- ☐ I have a comment

| Comment on linking performance outcomes & probabilities: |
|---|

8.5 We model uncertainty in future investment budgets allocated to PIP execution.

- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on modelling PIP budget uncertainty: |
|---|

8.5.1 Our budget uncertainty modelling links specific outcomes to specific probabilities.

- ○ We do not model future PIP budget uncertainty.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment

| Comment on<br>linking future PIP<br>budget outcomes<br>& probabilities: |
|---|

8.6 We model the risk of the entire investment portfolio exceeding its budget (affordability risk).

- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on<br>modelling PIP<br>affordability risk: |
|---|

8.6.1 Our PIP affordability risk modelling links specific outcomes to specific probabilities.

- ○ We do not model PIP affordability risk.
- ○ Strongly disagree
- ○ Tend to disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on linking PIP affordability outcomes & probabilities: |
|---|

8.7 We identify the range of likely outcomes and their probabilities from implementing the PIP as it evolves.

- ○ We do not model PIP risks.
- ○ Strongly disagree
- ○ Slightly disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| Comment on identifying the range & probabilities of PIP outcomes: |
|---|

8.8 We model the impact of information uncertainty on our portfolio conclusions.

- ○ Strongly disagree
- ○ Slightly disagree
- ○ Neither agree nor disagree
- ○ Tend to agree
- ○ Strongly agree
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I don't have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| Comment on information uncertainty impact on PIP: |

## Part 9 – RESOURCE LIMITATIONS

9.1 **Please indicate how the following potential resource limitations are addressed in your ND Investment Planning Process:**

9.1.1 **Available ND investment funding**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

**Comment on Available ND investment funding:**

9.1.2 **ND Research & Development capacity**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

**Comment on ND Research & Development capacity:**

9.1 **Please indicate how the following potential resource limitations are addressed in your ND Investment Planning Process:**

9.1.3 **ND project management capacity**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| **Comment on ND project management capacity:** |

9.1.4 **The capacity of ND facilities involved in the execution of certain investments**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Other (Please comment below.)
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ☐ I have a comment:

| |
|---|
| **Comment on The capacity of ND facilities involved in the execution of certain investments:** |

9.1 **Please indicate how the following potential resource limitations are addressed in your ND Investment Planning Process:**

9.1.5 **Seasonally or periodically available ND investment execution services**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| **Comment on Seasonally or periodically available ND investment execution services:** |

9.1.6 **Space in which to house investment deliverables**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| **Comment on Space in which to house investment deliverables:** |

9.1 **Please indicate how the following potential resource limitations are addressed in your ND Investment Planning Process:**

9.1.7 **ND logistic capacity to transport deliverables and their provisions**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| **Comment on ND logistic capacity to transport deliverables and their provisions:** |

9.1.8 **Size & maturity of ND occupational categories of personnel that will use deliverables**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| **Comment on Size & maturity of ND occupational categories of personnel that will use deliverables:** |

9.1 **Please indicate how the following potential resource limitations are addressed in your ND Investment Planning Process:**

9.1.9 **ND training capacity**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

**Comment on ND training capacity:**

9.1.10 **ND maintenance capacity**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

**Comment on ND maintenance capacity:**

9.1 **Please indicate how the following potential resource limitations are addressed in your ND Investment Planning Process:**

9.1.11 **Annual ND operating budgets**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| **Comment on Annual ND operating budgets:** |

9.1.12 **Engineering capacity to execute / support mid-life upgrades to deliverables**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| **Comment on Engineering capacity to execute / support mid-life upgrades to deliverables:** |

9.1 **Please indicate how the following potential resource limitations are addressed in your ND Investment Planning Process:**

9.1.13 **Capacity to dispose / divest of deliverables at end of life**

- ○ This is not a limiting resource.
- ○ This is addressed outside of portfolio planning.
- ○ This is routinely discussed during portfolio planning.
- ○ This is numerically modelled for portfolio planning disccussions.
- ○ This is a firm constraint on the portfolio.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| **Comment on Capacity to dispose / divest of deliverables at end of life:** |

9.1.14 **Other limited resource 1:**

- ○ There is another limited resource to be considered:
  - ○ This is addressed outside of portfolio planning.
  - ○ This is routinely discussed during portfolio planning.
  - ○ This is numerically modelled for portfolio planning disccussions.
  - ○ This is a firm constraint on the portfolio.
- ○ There are no limited resources to be considered outside of those listed above.
- ○ Information sensitivity prevents me from answering.
- ○ I would answer in a classified survey, but not here.
- ○ I do not have that information.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| |
|---|
| **Comment on Other limited resource 1:** |

9.1 **Please indicate how the following potential resource limitations are addressed in your ND Investment Planning Process:**

9.1.15 **Other limited resource 2:**

There is another limited resource to be considered:

- This is addressed outside of portfolio planning.
- This is routinely discussed during portfolio planning.
- This is numerically modelled for portfolio planning disccussions.
- This is a firm constraint on the portfolio.

- There are no limited resources to be considered outside of those listed above.
- Information sensitivity prevents me from answering.
- I would answer in a classified survey, but not here.
- I do not have that information.
- Other (Please comment below.)
- ☐ I have a comment:

**Comment on Other limited resource 2:**

9.1.16 **Other limited resource 3**

There is another limited resource to be considered:

- This is addressed outside of portfolio planning.
- This is routinely discussed during portfolio planning.
- This is numerically modelled for portfolio planning disccussions.
- This is a firm constraint on the portfolio.

- There are no limited resources to be considered outside of those listed above.
- Information sensitivity prevents me from answering.
- I would answer in a classified survey, but not here.
- I do not have that information.
- Other (Please comment below.)
- ☐ I have a comment:

**Comment on Other limited resource 3:**

## Part 10 – SURVEY CONCLUSION

10.1 Are there notable features of your ND investment planning not addressed in this survey?

- ○ The survey has already touched on every notable aspect of our ND investment planning.
- ○ There are other notable aspects of how we plan ND investments that the survey has not already addressed, that I would like to describe:
- ○ There are other notable aspects of how we plan ND investments that the survey has not already addressed, but they are too sensitive to share.
- ○ There are other notable aspects of how we plan ND investments that the survey has not already addressed that I would share in a classified survey, but not here.
- ○ I do not know whether or not there are any other notable aspects of how we plan ND investments that the survey has not already addressed.
- ○ Other (Please comment below.)
- ☐ I have a comment:

| **Comment on unaddressed aspects of ND investment planning:** |
|---|
| **Unaddressed aspects of our ND investment planning:** |

10.2 If you have any comments to offer on the survey questionnaire or your experience completing it, we invite you to share them.

- ○ I have no comments to make.
- ○ I would like to comment:

| **The survey questionnaire and my experience of completing it:** |
|---|

# REPORT DOCUMENTATION PAGE

| 1. Recipient's Reference | 2. Originator's References | 3. Further Reference | 4. Security Classification of Document |
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Capital investment prioritization; Decision analysis; Decision conferencing; Decision frame; Decision quality; Dialogue decision process; Operational research; Portfolio analysis; Portfolio decisions; Stakeholder engagement; Systems analysis; Values and trade-offs

**14. Abstract**

Defence Investment Prioritization (DIP) decisions are among the most difficult any nation makes. Challenges include complex military system interdependency, the significant cost of equipping military forces, distinct interests and cultures of military, political and commercial stakeholders and, most of all, uncertain future defence needs. This study offers valuable guidance to help build defence capital investment portfolios that realize desired long term national and alliance outcomes, combining insights from the relevant literature (operational research, systems analysis, decision analysis, etc.) with the results of a survey of national DIP practices. Responses from thirteen nations reveal a desire for more and better analysis and, in particular, a wide diversity in most aspects of national practice. This suggests a need less for procedures than for principles to govern sound long-term defence investments. Six Decision Quality (DQ) perspectives are proposed to manage the organizational, technical, analytical and uncertainty-based complexities of DIP. This framework offers analysts and decision-makers guidance in setting DQ goals and help in evaluating progress in building cost-effective portfolio alternatives to consider in the search for the best possible DIP portfolio.

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