How Much Science Is Enough?

Nicola S. Cox & Duncan R. Farr[1]

Abstract

A balance of investment study has been carried out to determine the optimum portfolio of capabilities across the Atomic Weapon Establishment's (AWE's) Technology Division, in order to inform strategic decision making. This study set out to examine the prioritization and required investment of the available program options to deliver a sustainable capability in technologies that meets both customer and business needs. To achieve this, discrete capability levels were derived from an examination of standards. The appropriate capability profiles for a number of given scenarios were then developed. Within these profiles a cost-benefit analysis was performed, using a multiple criteria decision analysis method. Costs were considered in terms of staff resources and benefits were derived from key program, business and customer drivers. This paper presents the method and general findings of the study.

Introduction

Background

Within a finite resource and funding profile, AWE's Technology Division needs to deliver a sustainable capability in its technologies to support both current and future program needs. In a period of change, and against the backdrop of the current economic climate, optimizing efficiency is crucial to achieving the required capabilities with a finite resource.

Scope

A cost-benefit analysis and a multiple criteria decision analysis (MCDA)[2] approach have been used to address the balance of investment in a logical and quantitative

[1] Atomic Weapons Establishment, UK.

manner. The balance of investment study was split into two stages: the first was a scenario based analysis of capability profiles for the Technology Division. Capability levels were defined and the minimum necessary capability level for each technology area was determined for a number of scenarios. The relative efficiencies of these capability profiles[3] were then investigated through comparison with an optimal capability profile. The second stage of the study expands on this, exploring the balance of investment across the individual technical products within each technology area.

This paper presents the method and findings of the first stage of the study. It considers the optimum balance of capabilities for the Technology Division and provides a framework to support strategic decision making and inform resource allocation.

Capability Levels

Defining Capability

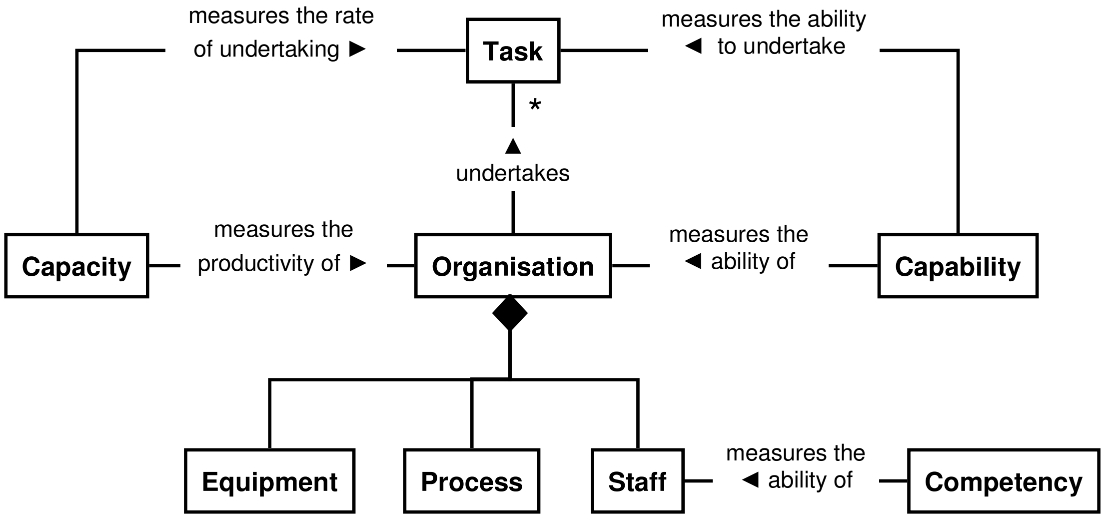
To determine the optimum balance of investment for an organization, consideration of the organization's capability, capacity and its staff's competency is essential. An organization is composed of its equipment (or facilities), its processes (or ways of working) and its staff. For each of the tasks that an organization undertakes, its capability measures its ability to complete that task and this depends on its equipment, processes and staff. Maintaining or developing capability therefore relies on a balanced investment across each area.

The capacity of an organization measures the organization's productivity, or rate of undertaking its tasks. This depends on the organization's equipment, processes and staff, and therefore maintaining capacity also relies on a balanced investment across each area. A level of capacity has been assumed in this study for each technology area and it has also been assumed that a competent body of staff is in place.

---

[2] MCDA is a decision making method in which the best solution to a defined problem is chosen from a set of discrete alternatives, on the basis of the performance of each alternative against a number of criteria.

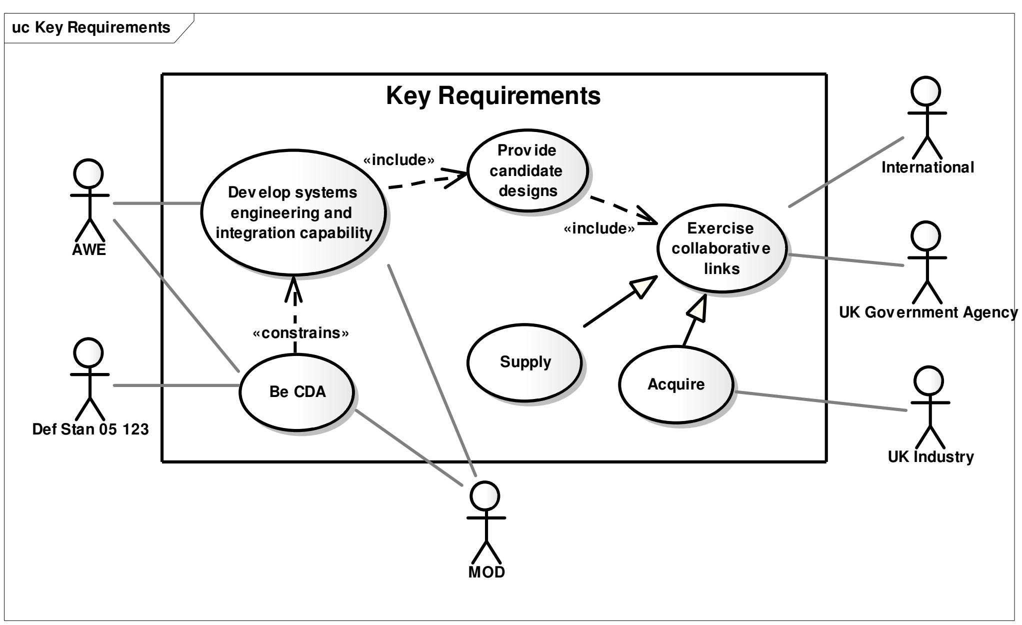
[3] A capability profile describes a set of capability levels, with a different level for each technology area within the Technology Division.



Defining capability within an organization

Capability Requirements

Five discrete capability levels were defined as part of this study using the Technology Division's key requirements, derived from consideration of AWE's contractual requirements, systems engineering standards and the Ministry of Defence (MOD)'s requirements for Coordinating Design Organisation (CDO). These are shown below.



Key requirements for the Technology Division

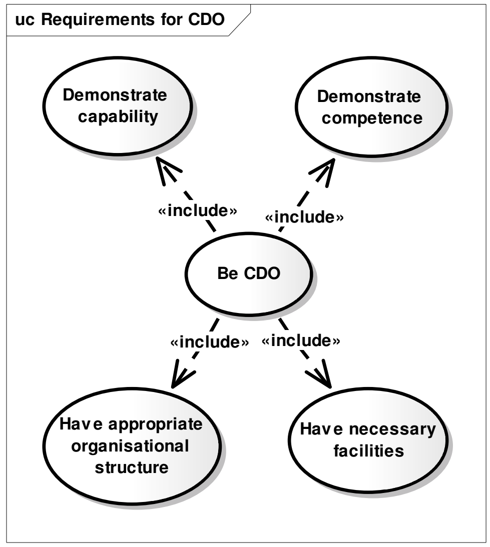
The Technology Division is required to develop its systems engineering and systems integration capability. This is seen by the MOD as a key enabler to the successful delivery of complex systems, as discussed in section B1 of the MOD's Defence Industrial Strategy[4]. Key aspects of systems engineering are an iterative systematic approach utilizing systems thinking and domain knowledge to progressively reduce risk.

To exercise and develop its systems engineering capability, the Technology Division produces candidate designs, which includes development of materials, the design of sub-systems, modeling and integration. This is carried out through establishing and exercising collaborative links with both the US, UK industry and other UK government agencies, in line with AWE's collaboration strategies. AWE may take either a supplier or a procurer role in any of these collaborations.

There is an additional requirement that AWE fulfils the requirements of CDO, as defined in Defence Standard 05-123[5]. As the MOD Coordinating Design Authority (CDA) for the nuclear warhead has appointed AWE as the CDO for the Trident warhead and for potential successor warhead candidates, AWE is responsible for overall warhead design and for co-coordinating the design of all sub-systems. As set out in the standard, this means demonstrating the capability, competence and appropriate organizational structures (with defined responsibilities) as well as the necessary facilities (particularly test facilities) to undertake this role. This is depicted in the image on the next page.

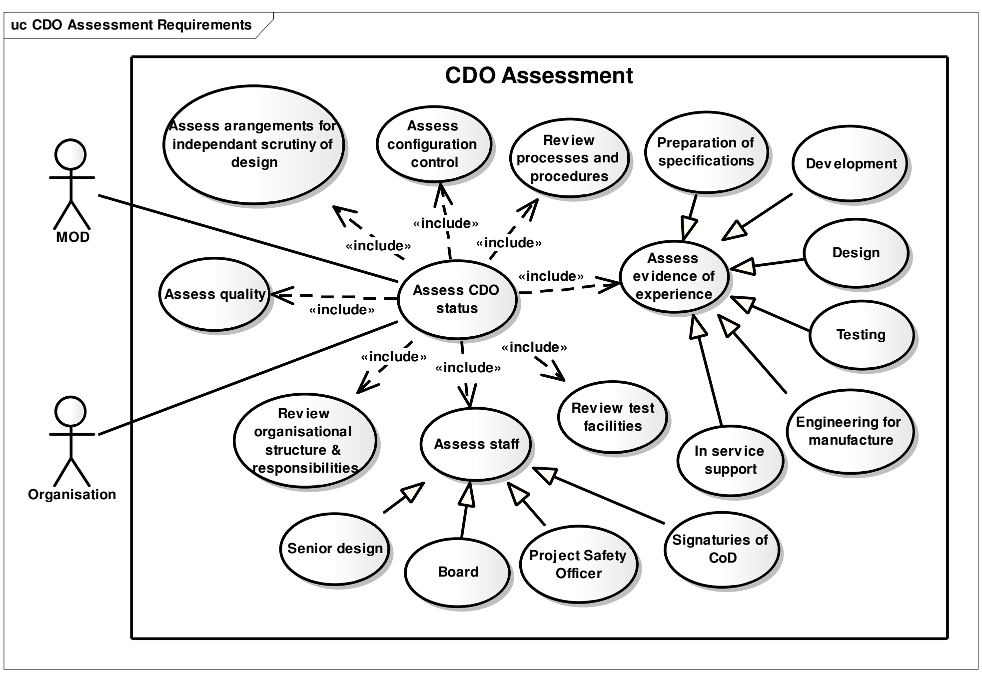
[4] Ministry of Defence, "Defence Industrial Strategy Defence White Paper" (December 2005)

[5] Ministry of Defence, "Defence Standard 05-123, Part 1: Technical Procedures for the Procurement of Aircraft, Weapons and Electronic Systems, Part 1 – Approval Procedure and Responsibilities", Issue 2, (29th October 2004).



Requirements for a Coordinating Design Organization

Demonstration of CDO status is undertaken through an MOD assessment, the scope of which is outlined in the next figure. The assessment requires evidence of experience of design, development, preparation of specifications, engineering for manufacture, testing and in-service support for the classes of products or services considered. At AWE, this portfolio of experience is spread across the Trident, Capability and Successor Directorates. The assessment also considers the adequacy of controls and governance arrangements and the competency of staff.



Requirements for Coordinating Design Organization assessment

Capability Level Definitions

The capability level definitions are based on the premise that in all cases, AWE is the CDO for the warhead and therefore must have a supplier level of capability at the warhead level of abstraction. For the warhead sub systems however, AWE may choose to outsource some of the required capability. In the technology areas that support warhead sub systems, AWE may not therefore need to have a supplier level of capability. The capability levels are summarized as follows:

Procurement Agency[6] (PA)

At the procurement agency capability level, AWE sources the sub system from another Design Organisation (DO). AWE has some knowledge of the sub system application, operating principles and design and is able to specify it and ensure the adequacy of its testing.

Partially Met Expert Customer (PMEC)

At the partially met expert customer capability level, AWE still sources the sub system from another DO but has some knowledge of critical functions and is able to inform the safety case. AWE is also able to analyze existing designs and peer review tests.

Expert Customer (EC)

At the expert customer capability level, AWE is now the DO for the sub system and must have demonstrably competent staff in place. The design, manufacture, testing and in-service support are still outsourced but AWE has experience of these areas and takes responsibility for the design.

---

[6] Note that this is similar to the 'intelligent customer' term that has previously been used within AWE. However, this does not have the same meaning as the intelligent customer concept developed by the Nuclear Installations Inspectorate (NII), which has gained international acceptance and is compatible with IAEA expectations. To avoid any confusion, the procurement agency terminology has been used instead. See Nuclear Installations Inspectorate, "Licensee use of contractors and intelligent customer capability", Issue 3, T/AST/049 (September 2009).

Design House (DH)

At the design house capability level, AWE has experienced staff, processes, procedures and quality assurance in place. All aspects of design, test and in-service support are carried out on site with just the manufacturing outsourced.

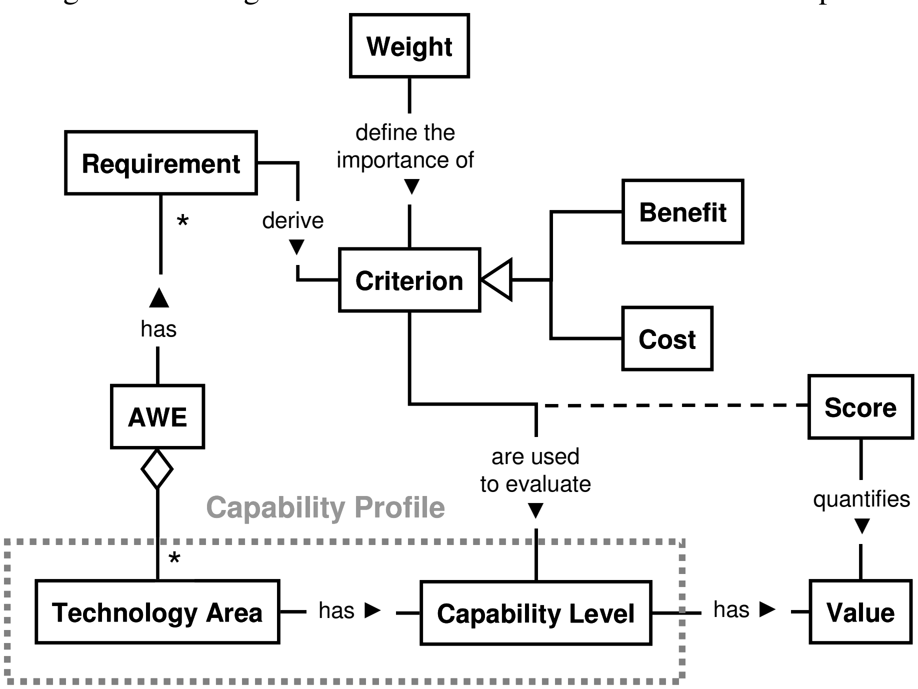
Supplier (S)

At the supplier capability level, AWE now has plants and equipment in place. All aspects of design, test, manufacture and in-service support are carried out on site.

Method

Overview

The MCDA technique was used to undertake a cost-benefit analysis for the technology areas within the Technology Division and explore potential capability profiles. The 'value' of each capability level for each technology area was quantified through its scores against a set of cost-benefit criteria. This is depicted below.

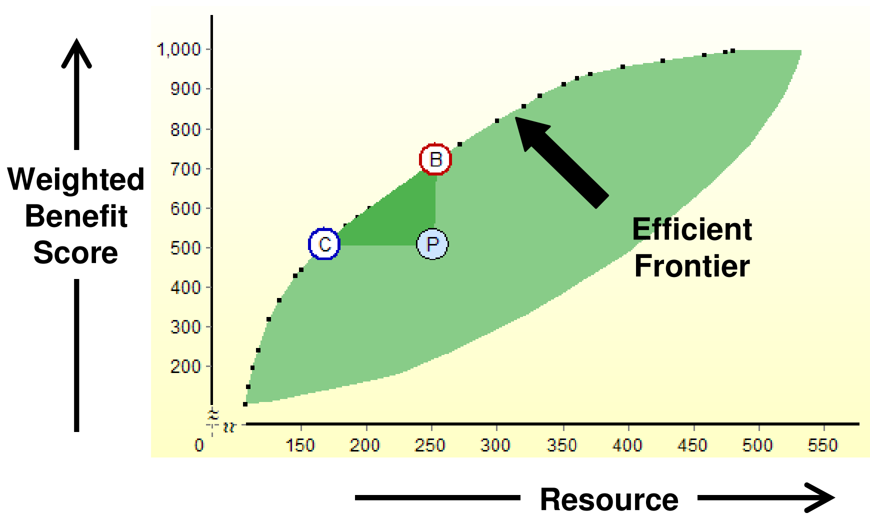


Balance of investment methodology

The total weighted score of each capability level was calculated by combining the weights with the scores against the criteria. A cost-benefit 'envelope'

was then constructed, using the software tool Equity,[7], containing the costs and benefits of every possible capability profile. Benefits were traded against the available resources, with the aim of finding the most effective utilization within the organization constraints.

Below is an example of a cost-benefit graph. The large shaded area in the graph represents the cost-benefit envelope within which all possible capability profiles lie. The top edge of the envelope forms the 'efficient frontier.' The most cost-efficient capability profiles are those that lie on this edge for which the greatest benefits at any given cost are possible. In this example, a less efficient capability profile 'P' has been selected where the darker shaded triangle highlights its distance from the efficient frontier. A 'cheaper' capability profile 'C' is highlighted on the graph. This profile achieves a similar level of benefit for a reduced cost. Conversely, a 'better' capability profile 'B' achieves greater benefits for a similar cost.



Example of a cost-benefit 'envelope'

Decision Criteria and Scoring Mechanisms

Staff resource needs for each capability level were used to quantify costs. Three benefit criteria were derived from a review of the Technology Division strategy and these were:

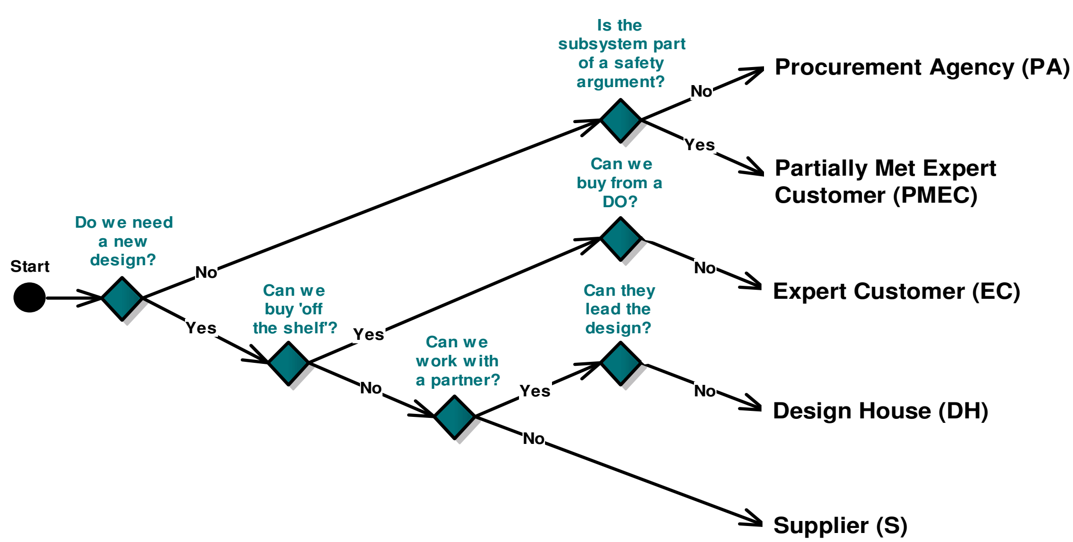
- Support the in-service system

[7] Equity is a decision modeling tool that uses MCDA techniques to construct the most efficient portfolio of investment or expenditure.

- Support international exchange
- Support future options

To assess the options against these criteria, scoring mechanisms were developed to allow the benefits to be measured in a quantifiable manner. Each capability level in each technology area was assessed against the criteria and assigned a numeric score on the basis of how well it fulfils them.

Scores for the 'support in-service system' criterion were based on the degree to which critical safety or performance issues can be responded to at the capability level in question. Scores for the 'support international exchange' criterion depend on how much international interaction is possible. Note that these will not necessarily increase at the same pace across all the technology areas. For the 'support future options' criterion, the required capability level for each technology area was determined by using the decision tree shown below to assess a number of potential future options. Scores were then assigned according to how many of the options each capability level would be able to support.



Capability level decision tree

Weights Rationale

Two types of weights were used in the study: within criterion weights and across criterion weights. The three across criterion weights reflect the relative importance of each criterion with respect to the others. The within criterion weights reflect the

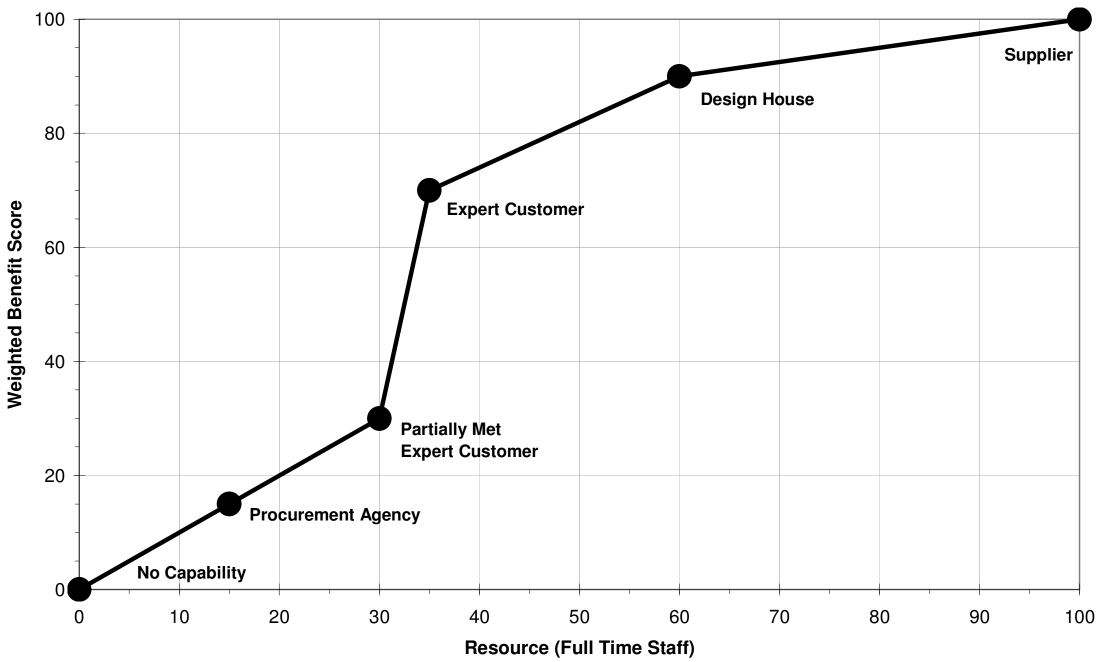
relative importance of each technology area for a given criterion. Within each criterion, the highest weight is given to the technology area(s) for which it makes the greatest difference if there is no investment in that area.

The rationale for the within criterion weights for the ‘support in-service system’ criterion was to assign the weights on the basis of safety-criticality, by assigning the highest weights to the technology areas that support safety-critical parts of the in-service system. For the ‘support international exchange’ criterion, weights were assigned on the basis of how important international exchange is for each technology area. For the ‘support future options’ criterion, weights were assigned on the basis of whether the technology areas support discretionary or non-discretionary[8] warhead elements.

Findings

Having investigated the efficiencies of various capability profiles for the Technology Division using the derived weights, benefit scores and costs, it was found that the trend to optimize the efficiency of the division with the available resources would be to narrow the scope of the technology programs and maintain only the minimum capability necessary for CDO status in each technology area. The remaining resources should then be focused to build up greater expertise in those technology areas that offer the greatest returns. This was found to be partly due to the ‘steps’ seen on the cost-benefit graphs for several of the individual technology areas: the weighted benefit scores increase rapidly with resource up until a pivotal point, beyond which the rate of increase is much lower and further investment does not yield significantly greater benefits. Thus the optimal balance of investment would be to invest enough resource in each area to reach this pivotal point. An example of such a ‘step’ is shown on the following page.

[8] Warhead elements that are essential parts of a modern warhead are termed ‘non-discretionary’. All other warhead elements are therefore discretionary.



Example of a cost-benefit 'step'

An additional implication of this finding is that there is no graceful degradation of capability as resource is reduced. It is therefore more efficient for the company to concentrate affordability-driven resource reductions on individual areas rather than distribute them across all areas.

Limitations and Sensitivities

The quality of the study is dependent on ensuring that the information used is accurate and representative and that the criteria, their scoring mechanisms and their weights are truly representative of the decision makers' concerns. Sensitivity to the weights was analyzed by comparison of the outcomes generated using different sets of weights, and it was found that the sensitivity was low (i.e. the choice of weights had little effect) for the majority of technology areas. Sensitivities to errors or inconsistencies within the data were not explored in this study, although iterations of the analysis indicate that small variations in the data can influence the outcome; error bars are also likely to vary between technology areas. Whilst comparisons with historical data do provide some credence and the findings of the study may used with confidence in an indicative manner, it is not recommended that they should be used mechanistically.

In addition, multiple criteria decision analysis is a method designed to determine the optimum balance of investment across a number of competing investment options. In this study however, the technology areas and their products may not be independent. This complexity of shared capabilities was not addressed by the study and should therefore be kept in mind when reviewing the findings.

Conclusions

In addition to providing useful recommendations for technology program prioritizations and technical strategy development, the study also successfully defined a framework for strategic decision making that draws on the judgment and experience of the subject matter experts in a robust and quantitative manner. In light of program, business and customer drivers, a cost-benefit model was developed to explore the optimum balance of capabilities for the Technology Division, using the concept of capability levels. The capability level definitions will also provide a valuable tool for capability based discussions.

Consideration of competency profiles and ‘soft skills’ may be an important area for further work, particularly in areas where the numbers of staff are relatively low. Achieving the necessary capabilities with limited resource requires careful management; protecting essential core subject matter experts whilst ‘churning’ staff between different technology areas and projects may be a solution that develops an agile workforce with the necessary breadth and depth of experience.