NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

AC/323(SAS-092)TP/875

www.sto.nato.int

STO TECHNICAL REPORT **TR-SAS-092**

Costing Support to Force Structure Studies

(Soutien à la détermination des coûts pour les études sur les structures de forces)

Final report of SAS-092.

Published July 2020

Distribution and Availability on Back Cover

NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

AC/323(SAS-092)TP/875

www.sto.nato.int

STO TECHNICAL REPORT **TR-SAS-092**

Costing Support to Force Structure Studies

(Soutien à la détermination des coûts pour
les études sur les structures de forces)

Final report of SAS-092.

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.

The content of this publication has been reproduced directly from material supplied by STO or the authors.

Published July 2020

ISBN 978-92-837-2199-4

Table of Contents

List of Figures

List of Tables

SAS-092 Membership List

CHAIR

Mr. Anthony G. KING
Dstl
UNITED KINGDOM
Email: agking@dstl.gov.uk

MEMBERS

Mr. James FREEMANTLE
Dstl
UNITED KINGDOM
Email: jlfreemantle@dstl.gov.uk

Mr. Jens LUSUA
FOI – Totalforsvarets forskningsinstitut
SWEDEN
Email: jens.lusua@foi.se

Mr. Arne MJELVA
Norwegian Defence Research Establishment (FFI)
NORWAY
Email: arne.mjelva@ffi.no

Mr. Peter NORDLUND
FOI – Totalforsvarets forskningsinstitut
SWEDEN
Email: peter.nordlund@foi.se

Mr. Mark REMPEL
DRDC
CANADA
Email: mark.rempel@forces.gc.ca

Mr. Dagfinn VATNE
Norwegian Defence Research Establishment (FFI)
NORWAY
Email: Dagfinn-Furnes.Vatne@ffi.no

Costing Support to Force Structure Studies

(STO-TR-SAS-092)

Executive Summary

SAS-092 ran from 2011 to 2015 with the purpose of developing "a common methodology for Capability Costing and Cost Analysis as part of Force Structure Studies." Cost analysis for force structure studies are hugely beneficial to decision makers who have the job of making best use of limited resources to achieve defence aims.

The panel aimed to provide guidance for nations whose force structure costing capability was not as mature as those nations participating, while at the same time making a scientific contribution to this field.

The panel concluded:

- It is important to define risk and develop quantitative models to assess it, including the human component. The reference case model allows for our biases to be reduced somewhat as long as we are truthful in the reference class we choose, and then thorough in our application. Failure to do either of these effectively will mean that the status quo will be maintained, that quantitative models will continue to provide us information that a project is affordable while history shows that it is not. This topic is discussed in Chapter 3.
- Seven topics related to a force structure's cost risk are identified that, if possible, should be included in a costing study. These are discussed in Chapter 4.
- The quality of the cost risk visualizations ultimately is determined by the ability of an analyst to turn the concepts discussed into reality. Armed with the visualization guidelines and risk visualization framework, an analyst has the necessary tools to create simple and effective visualizations that ease the communication a force structure's cost risks with decision makers. This topic is discussed in Chapter 4.
- Time-Driven Activity-Based Costing may be used to calculate the cost of capability. The method attributes force structure costs to capabilities based on the amount of readiness training the force structure conducts for the capabilities it provides. The cost of a capability is then the sum of the attributed costs plus the cost of readiness training. This method is presented in Chapter 6.

Soutien à la détermination des coûts pour les études sur les structures de forces

(STO-TR-SAS-092)

Synthèse

Le groupe de recherche SAS-092 a œuvré de 2011 à 2015 dans le but de développer « une méthodologie commune pour la détermination des coûts des capacités et l'analyse des coûts dans le cadre d'études sur les structures de forces ». L'analyse des coûts pour les études des structures de forces est extrêmement bénéfique pour les décideurs qui ont pour tâche de tirer le meilleur parti de ressources limitées afin d'atteindre les objectifs en matière de défense.

Le groupe avait pour objectif de fournir des orientations aux pays dont les capacités de détermination des coûts des structures de forces n'étaient pas aussi matures que celles des pays participants, tout en apportant une contribution scientifique à ce domaine.

Conclusions du panel :

- Il est important de définir le risque et de développer des modèles quantitatifs pour l'évaluer, y compris la composante humaine. Le modèle de cas de référence permet de réduire quelque peu nos biais, tant que nous sommes sincères dans notre choix de la classe de référence, puis minutieux dans notre étude. En cas de manquement à l'un de ces deux principes, le statu quo sera maintenu, les modèles quantitatifs continueront de nous indiquer que le projet est financièrement abordable, alors que l'histoire montre que ce n'est pas le cas. Ce sujet est abordé au chapitre 3.
- Sept points liés aux risques de coût pour une structure de forces ont été identifiés et, si possible, devraient être inclus dans une étude de coût. Ces points sont examinés au chapitre 4.
- La qualité de la visualisation des risques de coût dépend en fin de compte de la capacité d'un analyste à transformer les concepts discutés en réalité. Doté de directives de visualisation et d'un cadre de visualisation des risques, un analyste dispose des outils nécessaires pour créer des visualisations simples et efficaces facilitant la communication des risques de coût de la structure de forces aux décideurs. Ce sujet est abordé au chapitre 4.
- La méthode des coûts par activité pilotée par le temps (méthode TDABC) peut être utilisée pour calculer le coût de la capacité. La méthode attribue des coûts de structure de forces aux capacités en fonction du volume de la préparation opérationnelle que la structure de forces mène au regard des capacités qu'elle fournit. Le coût d'une capacité est alors la somme des coûts attribués et du coût de la préparation opérationnelle. Cette méthode est présentée au chapitre 6.

Chapter 1 – INTRODUCTION

At its Spring 2009 Panel Business meeting (PBM), the Systems Analysis and Studies (SAS) panel established an Exploratory Team (ET) on costing support for force structure studies SAS-092 was created out of this ET with the purpose of developing "a common methodology for Capability Costing and Cost Analysis as part of Force Structure Studies."

Cost analyses are an important part of long-term defence planning. In order to be able to define future force structures, it is imperative to be able to make good predictions of defence expenditures. Cost analysis for force structure studies are also hugely beneficial to decision-makers who have the job of making best use of limited resources to achieve defence aims.

Nations who participated throughout the life of the panel were Canada, Norway, Sweden and the UK. Estonia and Turkey were also participants for some of the duration of the panel.

At our first meeting, the panel refined the TA and Terms of Reference (TOR) and decided on the following areas of work:

- A comparison of the Cost Models used by panel member nations;
- Risk analysis for force structure costings;
- Visualization for cost risk analysis;
- Defence specific inflation and cost escalation; and finally
- Capability Costing.

Through studying these topics, the panel aimed to provide guidance for nations whose force structure costing capability was not as mature as those nations participating, while at the same time making a scientific contribution to this field.

The majority of the work was conducted between 2011 and 2015, when the final presentation to the SAS PBM was made. Since then, the panel has been largely in abeyance for which the chair takes full responsibility. This paper represents a historical record of the work conducted and a repository of the efforts of panel members.

Chapter 2 – COST MODEL COMPARISON

2.1 INTRODUCTION

A key element for costing outputs is how a nation is able to allocate costs beyond the input level and toward meaningful capability or tasks. In some businesses, this is relatively easy, for example in a manufacturing plant the cost of the machinery, labour, etc. can be divided up over the products created in order to inform the recommended retail price. This represents a relatively simple and small number of outputs as well as a small number of inputs. In defence, this equation is much more complex and, therefore, nations have developed differing ways of allocating costs to force elements.

2.1.1 Key Terms

The following terms have been used during the comparison process:

- **Input Costs:** Typical items, such as personnel costs, infrastructure and equipment. These are generally a key output from accounting systems and are used for budget management. However, they do not link to output and therefore are of limited used for budget management.
- **Force Elements, Supporting Elements and Overheads:** Understanding that there are a variety of elements within Defence including those that fight (Force Elements), those that train, support or accommodate (Supporting Elements such as airfields, barracks, etc.) and those that are the overhead of a department of state, for example, headquarters. Each model in the comparison has its own taxonomy, however, the components listed above feature in most of these (see Table 2-1).
- **Top Down:** A model that takes accounting data and allocates it out, based on an auditable process. The Canadian Strategic Cost Model (SCM) is an example of this method.
- **Bottom Up:** A model that estimates the cost of each individual element, for example the Swedish model, BEMPA.
- **Hybrid:** A mixture of top-down and bottom-up processes are used. The United Kingdom’s Force Structure Cost Model (FSCM) is an example of this.
- **Cost Outputs:** May range from Equivalent Annual Costs (EACs) to support balance investment analysis to cost profiles and personnel numbers to support affordability analysis.

Table 2-1: Comparison of Cost Models.

	UK	CAN	NOR	SWE	TUR
Comparator	**Force Structure Cost Model (FSCM)**	**Strategic Cost Model (SCM)**	**KOSTMOD**	**BEMPA**	**ORSA**
How long has the model existed for?	Created in 1999, in full use from 2002.	Created in 2005.	In development since 1970s (this version 2006 – 2009).	In service from 2006.	Started in 2007.
What is it used for?	Supporting high-level operational analysis used as a starting point for lower-level savings and to investigate the cost base.	The model is used for strategic planning – Strategic Review, Deficit Reduction Action Plan, Capability-Based Planning, etc. May be used to cost individual force structures – full cost.	A relatively easy and holistic model for estimating the costs in a branch and/or Defence systems. KOSTMOD is well suited for analysis of cost/effectiveness and cost/risk-aspects, as an integrated part of an analysis process.	Long-Term Planning of the Swedish Armed Forces.	Supporting decision-makers when planning the various strategic-level plans. Supports just the Navy, rather than all services.
Who does it support?	Main customers are the strategy (what does the future force look like) and capability (what is the equipment capability required?).	Strategic Planners, Strategic Initiatives.	Strategic planners.	Strategic planners, mainly in the Swedish Armed Forces. Identification of strategic issues for the Ministry of Defence.	Senior decision-makers.
Timescale for estimates – 10 years? 20 years? 30 years?	Plus/minus 50 years, although data quality is good for 10 years, and adequate for 30 years.	20 + years.	20 years.	Time horizons exceeding the more detailed short-term planning i.e., 10 – 25 years.	20 years.

	UK	CAN	NOR	SWE	TUR
Comparator	**Force Structure Cost Model (FSCM)**	**Strategic Cost Model (SCM)**	**KOSTMOD**	**BEMPA**	**ORSA**
What are the inputs?	Personnel numbers, high-level defence equipment data including procurement and in-service costs, capitation rates, MOD asset registers and ammo stock piles.	• Entities. Aggregated, based on enduring entities; • Direct costs; • Defence-specific inflation; • Cost category-specific inflation (e.g., military personnel, civilian personnel, equipment); • Attributions; • Capability cost profile and effects entities Effect: maritime → capability: Fleet HQ, surface combatant, submarines; • Budget, programs, replacements.	• Resources; units – equipment, personnel, barracks and establishments. sub-units. • Equipment; investment cost, Investment Cost Escalation factor (ICE), age distribution of stock, life expectancy, loss rate • Operating cost (4 levels, depending on pattern of use), Operating Cost Escalation factor (OCE).	• Force structure. • Description of each unit. • Personnel: Number of persons in different personnel categories, officers (per rank), NCO (per rank), reserve officers, soldiers, civil personnel. • Weapon systems /equipment: Numbers per type of system/ equipment. Cost of production unit, number of persons per category. • Price and cost data for personnel and weapon systems. • For simulations of need for recruitment: attrition rates in different career phases, "career patterns", personnel "flow"data. Costs of Int Ops = fixed sum.	Plans, efficiency plans, etc. There are up to 20 models that feed the model, and ORSA sits over the top of them.

	UK	CAN	NOR	SWE	TUR
Comparator	**Force Structure Cost Model (FSCM)**	**Strategic Cost Model (SCM)**	**KOSTMOD**	**BEMPA**	**ORSA**
Where do they come from?	Pan MOD, including centre (Equipment programmes, etc.) and the single services (personnel, etc.).	Defence Personnel, Operations and Maintenance Model (DPM), DND Economic Model, Capability Investment Database, National Procurement Database.	Defence budgets, defence accounts, logistics data, information from procurement projects, subject matter experts in defence organization.	Defence Budget/Plan.	Short-, medium- and long-term plans.
What does the model exclude (e.g., cost of operations)?	Peace time costs, e.g., What MOD plans to spend. In the UK, the cost of operations is met by the treasury and therefore are not of interest to the Dept.	Cost of operations, special programs. Not a cost-estimation model.	Actual cost of operations abroad has to be added manually.	Opportunity costs. Costs outside Defence Budget. No calculations of expenditures over time.	Fixed costs – the cost of the existing structure (different definition). This will be incorporated in the future.
How does the model manipulate the data?	Equipment data is mapped to **Master equipment types.** This speeds up the models' runtime. Equipment procurement is mapped to the equipment being procured. The model is constant cost, and therefore strips out inflation from the inputs.	Entities' direct costs that provide multiple capabilities are split into multiple entities Data validation is performed with an error of ±10% or $20 million. Cost attributions are assigned based on type of service required	Based on information on force structure and force structure development, costs are allocated to the relevant parts of the organization. Investment costs are added, based on the expected lifetime of equipment. Defence Specific Inflation is applied	Clustering of less costly equipment to area specific lump sums. Constant costs with a possibility of sensitivity analysis of changes in relative prices of the main resources: manpower and equipment.	Cost, personnel and effectiveness are in separate models. They draw information from the same databases, which ensures there is consistency.

	UK	CAN	NOR	SWE	TUR
Comparator	**Force Structure Cost Model (FSCM)**	**Strategic Cost Model (SCM)**	**KOSTMOD**	**BEMPA**	**ORSA**
How does the model manipulate the data? (cont'd)		Modernization programs, new programs, personnel changes are incorporated. Cost profiles are summations of direct costs plus costs of indirect entities using attributions. Defence-Specific Inflation is applied to create a 20+ year cost profile.			Data comes from various models, and this has to be manipulated to be used by the model. This can be by unit, down to the sub-unit level.
Why does it manipulate it in particular ways?	Due to computation time.	Largely driven by the usage of the DPM.	Not provided	To keep the model rather simple and not to overload it with detailed data.	Not provided
Is the model at constant cost or does it account for inflation?	Constant cost, with the ability to add in defence specific inflation when required.	Defence specific inflation is used.	Can use defence specific inflation such as Operating Cost Escalation, etc.	Constant cost i.e., fixed prices, but the model is able to cope with assumptions of defence-specific inflation / cost escalation.	Not provided
What are the cost outputs (e.g., force elements, capabilities, commodities)?	Force elements both generic and specific Units. The cost of indirect elements (e.g., shared and overheads) can also be factored in.	• Time dependent cost profile of each capability – grouped by effect – compared to proposed budget.	• 20-year cost profile for total force structure – results can also be analysed at force element level.	• Total costs of Force Structure (sub-output: "personnel" costs and "LCC for weapon systems/equipment").	• Budget "correctness" testing. • Split of budget to projects' detailed costs.

	UK	CAN	NOR	SWE	TUR
Comparator	**Force Structure Cost Model (FSCM)**	**Strategic Cost Model (SCM)**	**KOSTMOD**	**BEMPA**	**ORSA**
What are the cost outputs (e.g., force elements, capabilities, commodities)? (cont'd)	Capabilities have been costed in the past; however, this is difficult. Personnel data is also possible.	• Broken down by cost type – personnel, capital, O&M – direct/indirect. • Cost-benefit analysis – cost per asset is computed. • Military and Civilian personnel may be converted into personnel using the Cost Factors Manual.	• Cost types include personnel, equipment, infrastructure. • Operating costs and investment costs. • The model is useful as a reference for data concerning personnel numbers, equipment allocation, expected equipment lifetime, etc.	• Cost for each unit (same sub-outputs as above). • Manpower numbers per category. • Equipment numbers per equipment type. • The economic effects are valued as costs, not expenditures. • "Pricelist" of units as approximations for real-time force structure studies.	• Estimation of ordinary costs. • Budget in a specific year. • Split to financial branches. • Budget estimation.
Whole life costs, Equivalent Annual Costs, etc.?	Whole life costs broken into Development, Production, Personnel, and in-service. HLOA demands EACs as well. The data also exists to create a cost by DLOD.	Whole life cost and EAC.	Growth factors, life expectancy.	The economic calculations show annual costs for the Force Structure and its components (the different units) in a future steady-state situation.	Not provided
What other data does it provide (e.g., manpower numbers, equipment numbers)?	Personnel numbers, force element quantities, equipment numbers.	Not provided	Contains extensive data on personnel numbers, equipment allocation, expected lifetime of equipment, etc.	Personnel number per category, number of objects of more qualified equipment.	Not provided

	UK	CAN	NOR	SWE	TUR
Comparator	**Force Structure Cost Model (FSCM)**	**Strategic Cost Model (SCM)**	**KOSTMOD**	**BEMPA**	**ORSA**
Visualizations.	CoD Square method, CoD Target, various charts.	Simple bar charts and line graphs.	• Simple area graph (time by costs). • The model's extensive data output can be analysed with external tools.	Not provided	Not provided
What software does the tool use, e.g., databases?	Access 2007, with a VB.Net front end.	Original implementation is Microsoft Excel – data is extracted from departmental sources and copied into Excel worksheets. New version is migrated to Microsoft Access, Visual Basic, and Excel.	• Oracle. • Excel (VBa). • Powerbuilder (grensesnitt). • C++ (Algorithms).	• Excel • Visual Basic for Applications (VBA).	• Web-based model (the only one in the group). • Oracle. • Eclipse. • Java. • Optimisation: ILOG programme.
If code is used, what is it?	VB.Net.	Not provided	Operating the model does not require coding.	Not provided	Not provided
Issues supporting the software.	Model has just been extensively updated from VB and Access 97, to Access 2007 via Access 2003.	• Lack of design documentation. • Poorly designed Excel worksheets, very cumbersome to maintain and implement changes.	New version of model under development.	Not provided	Not provided

	UK	CAN	NOR	SWE	TUR
Comparator	**Force Structure Cost Model (FSCM)**	**Strategic Cost Model (SCM)**	**KOSTMOD**	**BEMPA**	**ORSA**
Issues supporting the software (cont'd).		• Summary of results is tedious and not automated. • Lack of consistent objective – model developed was *ad hoc* and sporadic. New version is much faster to support.	Use of model requires that the analyst has extensive knowledge of both the model itself and the force structure.	Not provided	Not provided
What is the tool particularly good at supporting?	High-level quick analysis.	High-level analysis, force structure studies, and capability-based planning.	Long term expected total force structure cost versus expected budgets. Facilitates strategic development of total force structure.	High-level analysis. Quick calculations during ongoing workshops.	• Quick decisions. • Web-based, easy to use, by many users. • Real-time information for decision. • Incorporates scientific approach.
What is the level of granularity it can provide?	Down to personnel and equipment types.	Supports strategic questions. Not for budgeting.	The structure is broken into pieces to a reasonable level of detail.	Uses rather aggregated data.	Not provided
Studies or people.	Not provided	Not provided	Not provided	Not provided	Not provided

	UK	CAN	NOR	SWE	TUR
Comparator	**Force Structure Cost Model (FSCM)**	**Strategic Cost Model (SCM)**	**KOSTMOD**	**BEMPA**	**ORSA**
Decisions that the tool has been used to influence.	Model supported analysis throughout the SDSR and 3-month exercise.	• Development of the Canada First Defence Strategy Strategic Review 2010. • Capability-Based Planning – Strategic Capability Roadmap. • Force structure investment projects.	Chief Head of Defence advice to NorMoD on future development of defence, most recently in 2015.	Influenced Sweden's major break away from conscription to voluntary force.	Not provided
Does the model aggregate costs or estimate them independently?	The FSCM takes some top-level outputs (equipment costs, as an example) and allocates these. Other costs, such as in-service and Manpower are estimated by the model. Additional analysis can be conducted to examine the impact of cost pressures, etc.	The model aggregates costs. It is not a cost estimation model.	The model aggregates costs, but the same analyst frequently estimate the input costs that are needed.	The model mainly aggregates costs to the force structure as a whole and the different units (normally battalions, divisions or corresponding units).	Not provided
Is data taken directly from sources for manipulation, or is it held in a central database?	Data is normalised in 5 databases within the model. This is held separate to the systems that provide the data.	The data is taken from existing databases for manipulation. The model is held separate from the actual data sources.	Data is gathered from many different sources and then manipulated by analyst before being put in the model.	The data is taken from existing databases for manipulation. The model is held separate from the actual data sources.	• Large quantities of data. Needs constant update.

	UK	CAN	NOR	SWE	TUR
Comparator	**Force Structure Cost Model (FSCM)**	**Strategic Cost Model (SCM)**	**KOSTMOD**	**BEMPA**	**ORSA**
Is data taken directly from sources for manipulation, or is it held in a central database? (cont'd)					• Database management. User trust. • Fixed costs. Data input automation. Risk analysis. • 10 officers, 2 programmers, 4 database planners.
Does the model support visualization methods? Are these built-in or conducted separately?	The model has rudimentary visualizations (bar charts, etc.) the team has a number of other methods, (squares, etc, that can be used during post processing).	The model has rudimentary visualizations (bar charts, etc.). External visualization tools are used to explore the data.	• Simple area graph (time by costs). • The model's extensive data output can be analysed with external tools.	No built-in visualizations.	The model has various visualizations, combining combat effectiveness, personnel, and cost. It brings all the outputs into one dashboard, which provides all the information to the commanders.
Is Defence-Specific inflation included within the model?	Recently incorporated into the model. Generally, though, DSI is incorporated in post processing.	Yes.	Yes.	Normally not, but the model is able to reserve for defence-specific inflation / cost escalation.	Not provided

Table 2-1 summarizes the models and clearly evidences that each model solves the issue of providing the cost of elements in different ways, as well as to different levels of resolution. In all cases, models are used to support high-level decision-making and to a lesser or greater extent have been used to support strategic reviews that have occurred in each participant country. In each case, models (and their owners) are beginning to understand the importance of data visualization in order to inform decision-makers. This has been shown in particular by the difference between an older model, for example the UKs FSCM which is reliant on post processing for visualization and the Turkish model ORSA which while it covers only the navy, is web based and able to present data in dashboards and other more recent visualization methods.

By comparing the models, it is clear that any method of costing capability costing based on these models will use the Force Element structure as its basis. Due to the whole force nature of the models, any defence inflation research will have to encompass the entire gamut of commodity blocks, not only focusing on equipment but also personnel, infrastructure and in-service support. All of the models have a capability to investigate and model risk to some extent. At the force structure level, risk will be aggregated and influenced by a number of dependencies between the units. Visualization is a key element for analysis in general but also for the force structure analysis. Many of the decisions that are supported by this calibre of model will be complex in nature and, therefore, need to be communicated in a simple manner.

Based on this comparison and tying in with the research interests of the group, the remainder of this report concentrates on cost risk analysis, defence-specific inflation and cost escalation (as a key component of force structure cost risk), cost risk visualization, and capability costing.

Chapter 3 – COST RISK ANALYSIS

3.1 INTRODUCTION

A force structure's lifecycle cost is inherently uncertain due to unknown future costs, such as acquisition costs, operations and maintenance costs, disposal costs, etc. Given the stochastic variability of these costs and the uncertainty of force structure parameters, such as fleet size, a point estimate of the lifecycle cost is not adequate to support decisions about how much funding a force structure need. Rather, to support decision-makers to make good decisions, force structure costing studies should include an expected lifecycle cost, its degree of total uncertainty[1], and a probability of the estimate occurring. Decision-makers can then use this information to select an appropriate contingency reserve that reflects their risk tolerance.

Many existing sources describe the process to perform a cost risk analysis [2], [3], [4], [5], [6]. In addition, previous NATO RTO task groups have either described or applied cost risk analysis and the generic process, as described in the SAS-054 task group report is shown in Figure 3-1 [1], [7], [8].

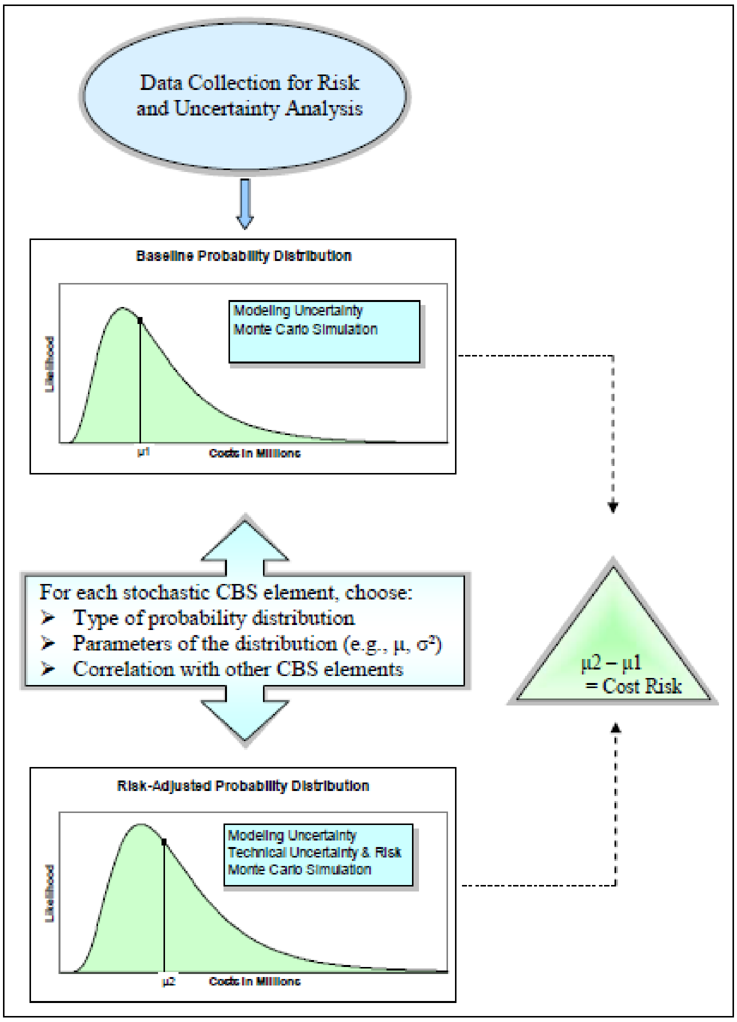

Figure 3-1: Process for Estimating Cost Risk and Uncertainty [1].

[1] Total uncertainty is defined as defined as the combination of uncertainty (i.e., lack of knowledge, also called epistemic uncertainty) and variability (i.e., effect of chance, also called aleatory uncertainty) [2].

As noted in the SAS-054 task group report, one of the most important and difficult aspects of estimating risk and uncertainty is data collection. While there are many data collection techniques, such as scorecards, historical data, and subject matter experts, force structure costing studies that are focused on systems that include new concepts and technologies for which little or no historical data or experience exists often rely upon expert opinion. This situation is just one instance when expert opinion may be used. Others include:

- The data simply have never been collected in the past;
- The data are too expensive to obtain;
- Past data are no longer relevant (new technology, changes in political or commercial environment, etc.);
- The data are sparse, requiring expert opinion 'to fill in the holes'; and
- The area being modelled is new [2].

Given that the process to conduct a risk analysis is well documented in existing sources and the importance of expert opinion in cost risk analysis of future force structures, this chapter focuses on the heuristics and biases that experts are susceptible to during the data collection process of expert opinion.

The remainder of this chapter is organized as follows. The next section presents definitions of terms. This is followed by a description of heuristics and biases that experts are susceptible to during the data collection process.

3.2 KEY TERMS

The terms *risk* and *uncertainty* are defined in many existing cost-estimating best practices guides (Table 3-1).

Table 3-1: Definitions of Risk and Uncertainty.

Risk	Uncertainty	Source
Exposure to loss. In a weapon system acquisition context, it is a measure of the potential inability to achieve overall programme objectives within defined cost, schedule, and technical constraints, and has two components: 1) The probability/likelihood of failing to achieve a particular outcome; and 2) The consequences/impacts of failing to achieve the outcome.	The indefiniteness or variance of an event. It captures the phenomenon of observations, favourable or unfavourable, failing to the left and right of a mean or median value.	SAS-054 [1].
A random event that may possibly occur and, if it did occur, would have a negative impact on the goals of the organization. Thus, a risk is composed of three elements: the scenario; its probability of occurrence; and the size of its impact if it did occur (either a fixed value or a distribution).	*Variability*: The effect of chance and is a function of the system. *Uncertainty*: The assessor's lack of knowledge (level of ignorance) about the parameters that characterize the physical system that is being modelled. *Total uncertainty*: Combination of uncertainty and variability.	Vose [2].

Risk	Uncertainty	Source
Chance of loss or injury. In a situation that includes favourable and unfavourable events, risk is the probability that an unfavourable event will occur.	The indefiniteness about the outcome of a situation. It is assessed in cost estimate models to estimate the risk (or probability) that a specific funding level will be exceeded.	United States Government Accountability Office [4].

Although the definition of *risk* is not significantly different (i.e., all definitions include probability and impact), the definition of *uncertainty* does differ. In particular, Vose (2008) provides the following definitions:

- *Variability* is defined as the effect of chance. This is not reducible through study or measurement.
- *Uncertainty* as the lack of knowledge about a parameter. This is reducible through study, measurement, or consulting more experts.
- *Total uncertainty* as the combination of uncertainty and variability [2].

Within the context of force structure costing studies, an example of variability is the probability distribution of a foreign exchange rate. An example of uncertainty is the confidence distribution of the number of vehicles in a proposed fleet, and the total uncertainty is the effect of both of these.

Separating variability and uncertainty within a cost risk analysis has the benefit that the total uncertainty can be described and separated in these terms. For example, if the majority of the total uncertainty is due to variability, then decision-makers know it is futile to collect more information about the force structure. However, if the majority of the total uncertainty is due to uncertainty, then collecting more information may help to reduce the total uncertainty.

3.3 PSYCHOLOGICAL ASPECTS OF RISK

In many cases, risk is taken into account during the forecasting process, and projects may still overrun, both in terms of cost as well as time. Indeed, in his 2009 review of UK defence acquisition, Bernard Gray identified that on average projects in the UK overrun in time by 81% and overrun in cost by 42% [9]. This systematic poor performance could be due to a limited control framework, but investment in projects is extensively governed by both the Department of Defence, through its guide to investment appraisal, as well as by HM Treasury whose Green Book outlines the methods and techniques that lead to a project being approved [10], [11]. It could also be due to poor project management, or the relationship with industry. Arguably, these seek to blame processes or another organization as these are easy fall guys. This section argues that risk, and failing to account for it, is much more to do with psychology than the overt processes mentioned above.

When making decisions, humans rarely weigh up all the options before coming to an answer; rather, we use a series a biases, stereotypes and analogies in order to inform our decision. Given the complex world in which we operate, by using these methods we are able to shorten the amount of time it takes to make a decision. In many cases, decision-making is done unconsciously, i.e., where our unconscious thinking informs our overt behaviour long before we are consciously aware of it [12]. This process is incredibly useful, however, as we struggle to articulate how we have come to these decisions empirically, using gut feeling in project management or leadership is rarely seen as a valid philosophy.

Flyvbjerg [13], in a summary of his earlier work [14], suggests that psychological and political explanations better account for inaccurate forecasts than modelling or incomplete data. Psychological elements are predominantly based around optimism bias, whereas political explanations are the result of strategic misrepresentation. Together, these elements form the Planning Fallacy.

3.3.1 Optimism Bias

Lovello and Kahneman outline a number of biases that are symptomatic in organizational decision-making, which have a profound impact on how organizations evaluate risk, primarily by reinforcing an optimistic approach to a project [15].

3.3.2 Anchoring

Anchoring is one of the strongest and persistent of all biases. It relates to the fact that, when we consider a new project, we will have an idea about what we expect the project to be, for example, a cost, a solution, etc. This plan will then be adapted in the light of requirements, funding and maturity. While this may seem to be a logical method, it leads to an over-optimistic evaluation of the project. Anchoring can be used to explain cost overrun in projects as since a value for risk will be included within a project, the decision-maker is 'anchored' to the initial estimate of the cost and, therefore, it is likely that the risk provision will not cover the cost of any overruns.

3.3.3 Competitor Neglect

Competitor neglect is a process where organizations fail to take into account the behaviours of their competitors, particularly when attempting to enter a new market, projections are made based on a monopoly rather than a crowded market. In the defence context, projects will be developed to exceed the current (or slightly future) capabilities of the current threat. They will rarely consider the full range of threat or a changing environment. In defence, this principle could also be applied to the relationship with monopolistic suppliers, as estimates will be created based on a project working correctly. In this case, the behaviours of the supplier will directly influence the price and the risk as Defence has no recourse or other options to supply the capability.

3.3.4 Organizational Pressure

In a defence environment, like the wider business environment there are limited resources that need to be invested. Therefore, there is competition between projects to be funded. As part of this process the cost estimate is key. In the UK, at least, it is rare that projects once in the programme are terminated, rather, review notes will increase the funding available over time, the one recent exception being the Nimrod Maritime Patrol Aircraft, which was cancelled as a result of the 2010 Strategic Defence and Security Review. Again, this behaviour is compounded by the relationship with industry as Gardener and Moffat illustrated using a game theoretical approach to defence acquisition [16]. In their study, the environment rewards industry for placing an overly optimistic bid while also rewarding defence project teams for accepting these bids as it allows them to get the project in the programme. If either of the parties were to take the better view for the entire portfolio, then the project is unlikely to be funded.

3.3.5 Confirmation Bias

While not featured in Lovello and Kahneman's work, another relevant bias for the risk forecasting is **Confirmation bias**. This is the effect to seek and interpret evidence in a manner that supports our conclusions. It has been well documented in scientific circles and a key tenet of the empirical falsification process created by Karl Popper who seeks to address this by stating that a theory can never be proven, but only proved false. This encourages the researcher to search for contrary evidence. In the case of financial markets, taking this approach removes bias and leads to investors making more money [17]. In defence, seeking evidence and interpreting it impartially would improve the accuracy of cost estimating and accounting for risk.

3.3.6 Political Elements

3.3.6.1 Strategic Misrepresentation

Strategic Misrepresentation is a more sinister version of optimism bias as rather than being the result of unconscious processing, it represents a more Machiavellian behaviour by using cunning as well as consciously misleading approval processes to make a project happen. Flyvbjerg demonstrates this in examples, including the Sydney Opera House where the political imperative was to have the project far enough into construction that it could not be stopped by an incoming administration [18]. To do this, the cost estimate, which was politically motivated rather than architect generated, was 1400% too low. Projects may also use other supporting evidence, for example, jobs generated or wider economic benefits. Flyvbjerg reports that these typically do not come to fruition. Worryingly, this was a pattern that was used to justify the 2012 Olympics, as well as the economic impact of the High Speed 2 network in the UK on Northern communities resulting Gardener and Moffat's paper also alludes to this, where both parties know that a bid is optimistic but both are incentivised to submit and accept this bid [16].

When taken together, these elements form the **Planning Fallacy,** and, as Kahneman and Tversky argue, even when we are aware of the biases, we will still make them, or fail to make a large enough allowance [19]. Kinsman and Tversky suggest that reference case forecasting be used in order to address this. Flyvbjerg has created a method for applying these principles in project management.

The impact of providing a reference class has a dramatic effect on the accuracy of individuals when they forecast performance. SAS 092, in March 2013, replicated a study conducted by Gilovich, Griffin and Kahneman and found that participants who were provided with a reference case for performance on a quiz were better at estimating their performance than those that did not have a reference case [20].

According to Lovello and Kahneman, reference case forecasting consists of five steps; these are:

1) Select a set of past projects to serve as your reference class. In defence, when considering a new fighter jet, we would consider similar jets that have done similar roles previously;

2) Assess the distribution of outcomes. Identify the average and extremes in the reference class projects' outcomes. An average cost for a jet may be £30m, however, this range could be up to £100m, and may also be driven by delays or reductions of platform numbers;

3) Predict your project's position in the distribution. Intuitively estimate where your project would fall along the reference class's distribution. This is akin to using our unconscious thought process to consider if the estimate feels right, given our prior knowledge;

4) Assess your prediction's reliability. Counteract your biased prediction from the previous step. Based on how well past predictions matched actual outcomes, estimate the correlation between your intuitive prediction and the actual outcome. Using the fighter jet example, costs are typically underestimated and, therefore, the reliability is likely to be poor; and

5) Correct your intuitive estimate. Adjust your intuitive prediction based on your predictability analysis. This would be used to create additional risk funding for the total programme [15].

Flyvbjerg applied this method to transport projects in the UK, creating reference classes for roads, railways and bridges among others [21]. Using this method, he was able to provide optimism bias uplift factors for these programmes. As a result, HM Treasury in its Green Book set out requirements for bias to be taken into consideration when evaluating project costs [11].

Thus, while it is important to define risk and develop quantitative models to assess it, more important and arguably the biggest cause of risk is the human component. The reference case model allows for our biases to be reduced somewhat, as long as we are truthful in the reference class we choose, e.g., comparing cost control in commercial airliners to fighter jets and then thorough in our application. Failure to do either of these effectively will mean that the status quo will be maintained; quantitative models will continue to provide us information that a project is affordable while history shows that it is not.

3.4 REFERENCES

[1] NATO RTO (2007). SAS-054 Methods and Models for Life Cycle Costing.

[2] Vose, D. (2008). Risk Analysis: A Quantitative Guide (3rd Ed.). John Wiley & Sons, Ltd.

[3] U.S. Air Force (2007). Cost Risk and Uncertainty Analysis Handbook.

[4] United States Government Accountability Office (2009). Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs.

[5] Ghanmi, A., Ghergari, V., Rempel, M., Sokri, A., and Solomon, B. (2014). Cost Risk Framework. Defence Research and Development Canada, DRDC-RDDC-2014-R167.

[6] NASA (2015). NASA Cost Estimating Handbook, Fourth Edition.

[7] NATO RTO (2009). SAS-069 Code of Practice for Life Cycle Costing.

[8] NATO RTO (2012). SAS-076 NATO Independent Cost Estimating and the Role of Life Cycle Cost Analysis in Managing the Defence Enterprise.

[9] Gray, B. (2009). Review of Acquisition for the Secretary of State for Defence: An Independent Review by Bernard Gray. London, UK Ministry of Defence / TSO.

[10] UK MOD (2014). Joint Service Publication 507: Investment Appraisal and Evaluation.

[11] HM Treasury (2003). The Green Book: Appraisal and Evaluation in Central Government, Treasury Guidance. London, TSO.

[12] Gladwell, M. (2005). Blink: The Power of Thinking Without Thinking. London, Penguin Books.

[13] Flyvbjerg, B. (2006). Curbing Optimism Bias and Strategic Misrepresentation in Planning: Reference Class Forecasting in Practice. European Planning Studies, 16(1).

[14] Flyvbjerg, B., Glenting, C., Rønnest, A., and COWI (2004). Procedures for Dealing with Optimism Bias in Transport Planning: Guidance Document. London, UK Dept for Transport.

[15] Lovello, D., and Kahneman, D. (2003). Delusions of Success: How Optimism Undermines Executives Decisions. Harvard Business Review. July 2003.

[16] Gardener. T., and Moffat, J. (2008). Changing Behaviours in Defence Acquisition: A Game Theory Approach. Journal of the Operational Research Society 59, pp. 225-230.

[17] Hilton, Denis J. (2001). The Psychology of Financial Decision-Making: Applications to Trading, Dealing, and Investment Analysis. Journal of Behavioral Finance 2(1), pp. 37-39.

[18] Flyvbjerg, B. (2005). Design by Deception: the Politics of Megaproject Approval. Harvard Design Magazine. Spring/Summer, pp. 50-59.

[19] Kahneman, D., and Tversky, A. (1979a). Prospect Theory: An Analysis of Decisions Under Risk. Econometrica 47, pp. 313-327.

[20] Gilovich, T., Griffin, D., and Kahneman. D. (Eds.) (2002). Heuristics and Biases: The Psychology of Intuitive Judgment. Cambridge, Cambridge University Press.

[21] Flyvbjerg, B. (2008). From Nobel Prize to Project Management: Getting Risks Right. Project Management Journal 35, 3, pp. 3-15.

Chapter 4 – COST RISK VISUALIZATION

4.1 INTRODUCTION

Effective communication between analysts and decision-makers is an important component of supporting force structure and capability investment decisions. To base these decisions on evidence requires sound assessment, analysis, and disclosure of force structure cost risks, risk responses, and subsequent residual risks. Given that risk assessments are difficult to understand [1], it is important that costing studies guide decision-makers through the assumptions, results, and conclusions (recommendations) in a manner that is transparent, cogent, and accessible.

To ensure that force structure costing studies are presented in a clear, logical, and convincing manner, they require: the identification and assessment of a force structure's cost risks; a sensitivity analysis for the cost risk breakdown structure, including scheduling, budgeting, and project control; and a contingency analysis that represents the cost of the risk responses. The ability to perform these analyses is dependent upon the type of model used (i.e., qualitative or quantitative); however, if possible, a force structure costing study should include the following seven items[1]:

- Assumptions used to calculate the force structure's base estimate cost, including selected bounds, distributions, and uncertainty in the data;
- Risks associated with the force structure's cost;
- A sensitivity analysis of the cost risk breakdown structure's elements;
- The correlations between the risks;
- The force structure's base estimate cost and its probability level;
- A cumulative distribution (S curve) of the force structure's cost in budget year dollars, including the probability of the base estimate and selected contingency level; and
- Risk-adjusted, in budget year dollars, costs by year to show phasing of risks.

Performing the above analyses is relatively straightforward, yet communicating the results can be a daunting task. In particular, probabilities (both independent and dependent events), which are vital to understanding risk analysis, are notoriously difficult for decision-makers to understand [3]. Using visualizations to communicate the analyses helps to alleviate this difficulty since our brains are better at extracting information from visualizations than from tables or sentences [4], [5]; however, this presentation format is not often used in practice. With this in mind, this chapter deals with the subject of cost risk visualization.

Previous NATO RTO activities have:

- Summarized human factors issues regarding visualization, types of data and their presentation, and described examples of visualization used within the military [6];
- Discussed how to use visualization to communicate results in lifecycle cost studies [7]; and
- Have used visualization to report risk in the development and production costs of assets [8].

Building on these works, the aim of this chapter is to provide guidance on how best to design visualizations that provide the required information to respond to the aforementioned seven points. The remainder of the chapter is organized as follows. First, we present examples that demonstrate how guidelines, such as how to

[1] This list is similar to the steps to develop a credible S curve that are described in the U.S. Government Accountability Office [2] (see p. 159).

encode data, from the academic literature can be applied to create effective visualizations. Next, we present a framework whose aim is to help analysts design risk visualizations. This is followed by detailed examples of how the framework can be applied to design visualizations for the seven aforementioned points. Lastly, we present a conclusion.

The chapter is partly built on a chapter in a scientific report written by one of the NATO SAS-092's members [9].

4.2 DESIGNING VISUALIZATIONS

The best practices in designing visualizations are well documented. From this literature, several important results may be used to inform the design of cost risk visualizations. These are:

- How our pre-attentive vision leads to visual encodings of that minimizes the amount of effort required to identify features in a visualization [10];
- Preferences for visual encodings of quantitative, ordinal, and categorical data that simplify the interpretation of visualizations [11], [12], [13], [14];
- General principles that lead to good visualizations [15], [16]; and
- A systematic framework for risk visualization [17].

Together, these provide analysts with guidance on how to design visualizations for communicating with decision-makers. In the remainder of this section, we present an example that demonstrates how the results from the first three items (i.e., pre-attentive vision, visual encodings, and general principles) are used to design a visualization. The risk visualization framework is presented in the next section. In addition, Appendix 4-1 has an extended discussion of pre-attentive vision, visual encodings, and general principles.

4.2.1 Example

The choice of how to visually encode data has a significant impact on a decision-maker's ability to interpret and gain insight from the data. A visualization that is commonly used to summarize categorical data or present different values of a given variable is a pie chart. An example is shown in Figure 4-1, where the chart shows the 2013 military expenditure (in constant 2011 US dollars) of NATO nations. While this chart clearly shows that the USA had the largest military expenditure, it is very difficult to compare the expenditures of other nations, such as FRA and GBR, CAN and TUR, etc.

Pie charts visually encode data using *angles*, where a larger angle represents a larger value. Cleveland and McGill showed that this encoding is not the best encoding to interpret quantitative data (see Figure 4A1-3 in Appendix 4-1) [12]. They found that individuals interpret quantitative data more accurately when it is encoded using *position* (most accurate encoding) or *length* (second most accurate encoding). A bar chart, which encodes data using *length* (i.e., longer bars reflect higher values), of the 2013 military expenditures (in constant 2011 US dollars) of NATO nations is shown in Figure 4-2. Similar to the pie chart, the bar chart clearly shows that the USA had the largest military expenditure. However, the visualization also clearly shows that GBR's expenditure was less than FRA and that CAN and TUR are very similar.

A further improvement is to encode the data using position. For example, Figure 4-3 shows a dot chart of the 2013 military expenditures (in constant 2011 US dollars) of NATO nations. Although this visualization is similar to the bar plot, the expenditures are encoded using the position (along the x-axis) using a dot rather than the length of a bar. Similar to the bar plot, it is straightforward to determine that the USA had the highest military expenditure and to compare the expenditures of two nations. In addition, this simple presentation of the data encourages decision-makers to see the trends in the data (i.e., countries may be grouped into three clusters:

1) USA, as it is an outlier;
2) TUR through FRA, given the linear trend; and
3) ESP through ALB, given a linear trend).

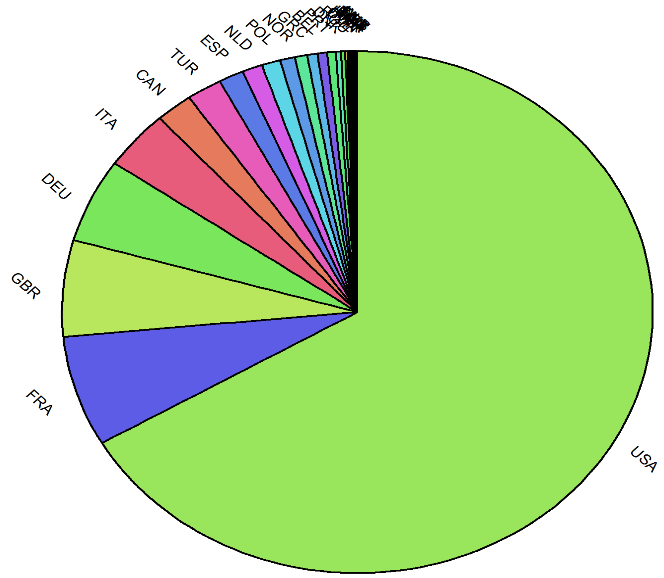

Figure 4-1: Pie Chart of the 2013 Military Expenditures of NATO Nations (in Constant 2011 US Dollars). Source: Stockholm International Peace Research Institute Military Expenditure Database.

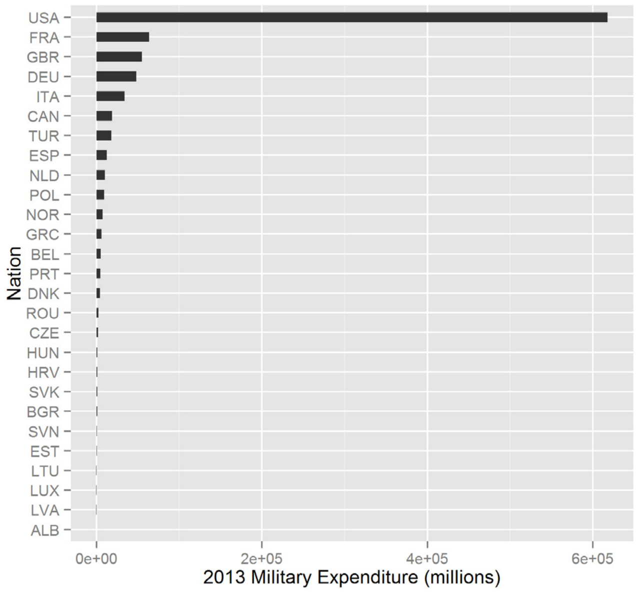

Figure 4-2: Bar Chart of the 2013 Military Expenditures of NATO Nations (in Constant 2011 US Dollars). Source: Stockholm International Peace Research Institute Military Expenditure Database.

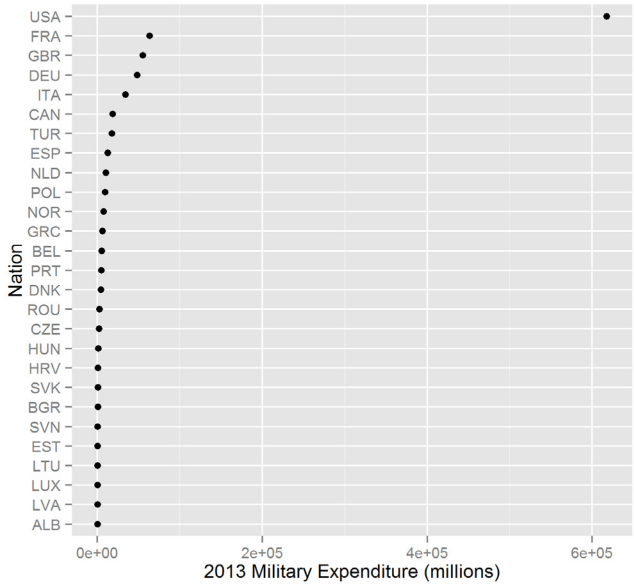

Figure 4-3: Dot Chart of the 2013 Military Expenditures of NATO Nations (in Constant 2011 US Dollars). Source: Stockholm International Peace Research Institute Military Expenditure Database.

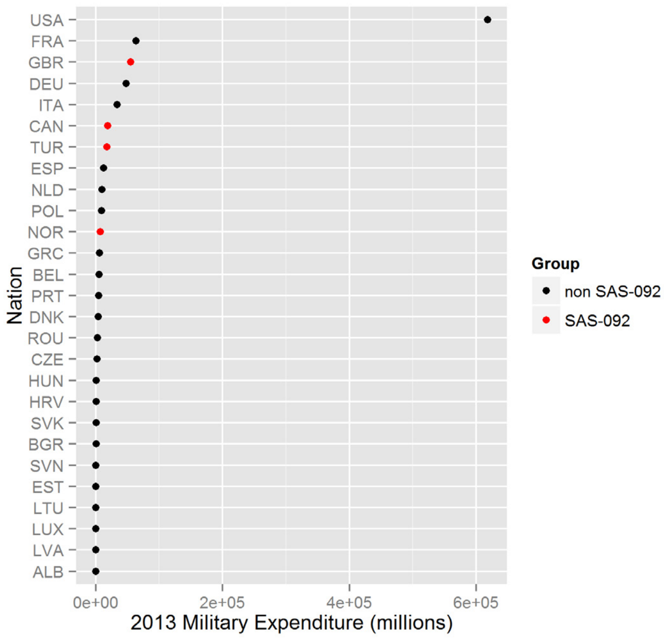

Figure 4-4: Dot Chart of the 2013 Military Expenditures of NATO Nations (in Constant 2011 US Dollars). Source: Stockholm International Peace Research Institute Military Expenditure Database.

Lastly, an understanding of human's pre-attentive vision can be used to highlight features in a visualization. For example, Figure 4-4 is identical to Figure 4-3 with the addition that NATO nations that are members of the SAS-092 task group are shown in red. Using colour in this manner leverages decision-makers pre-attentive vision to rapidly assess the visualization (i.e., within 200-250 milliseconds) and identify these countries.

4.3 COST RISK VISUALIZATION FRAMEWORK

Given the ability of visualization to ease the communication of information between individuals, visualization can be employed to help decision-makers better understand and manage risks. With this in mind, Eppler proposed a risk visualization framework with three specific aims [17]:

- Show the scope of risk visualization; that is, where and when can it provide tangible benefits;
- A checklist of factors to take into account when visualizing risks; and
- Show various representation formats to visualize risks.

This framework is designed to answer the *why*, *what*, *for whom*, *when*, and *how* questions of a risk visualization. The framework is shown in Figure 4-5.

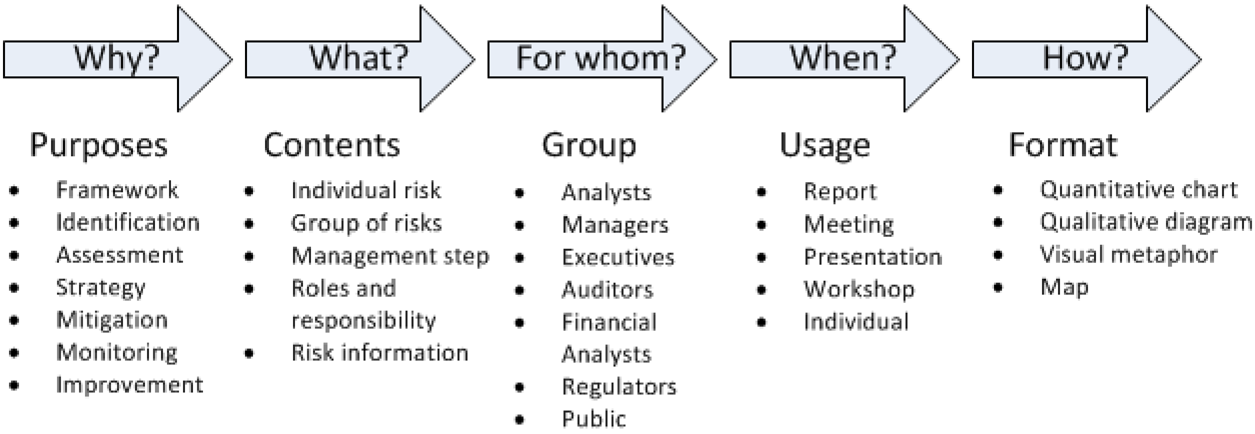

Figure 4-5: Risk Visualization Framework [17].

The *why* component of the framework addresses the potential uses of a risk visualization. For example, a visualization whose purpose it is to communicate a risk framework is different from one whose aim it is to show the distribution of a force structure's cost. The *what* component of the framework focuses on the contents that are depicted in a risk visualization. For example, a visualization may focus on an individual risk and its attributes, a group of risks and their relationships, or the risk response plan and various organization's responsibilities. The *for whom* component of the framework addresses the stakeholders for whom the visualization is designed. For example, analysts may want to understand risks only in their area of responsibility, managers and executives will require a much wider understanding of the organization's risks, and auditors will want to focus on residual risks and non-effective controls. The *when* component of the framework focuses on the actual usage of the visualization. For example, a risk report may require publication quality visualization, whereas a meeting with an individual only requires a basic illustration. Lastly, *how* addresses the format of the risk visualization: quantitative charts, qualitative or conceptual diagrams, maps, etc.

These five components provide the scope for when risk visualizations can provide tangible benefits. Likewise, the factors' components provide a checklist that should be considered when designing visualizations.

4.4 VISUALIZING FORCE STRUCTURE AND CAPABILITY COST RISK

The preceding sections provide visualization guidelines and a conceptual framework to help analysts design risk visualizations. In this section, we apply these concepts and show visualizations that provide answers to the seven points raised in this section's introduction. The remainder of this section is divided in six parts: one part for each point, with the exception of points five and six (i.e., project cost distribution and contingency level) that are presented together. In each part, we first frame the visualization using the Eppler and Aeschimann framework, and then suggest visualizations to respond to each point. The data shown in the force structure visualizations are similar to that shown in the 2013 Next Generation Fighter Capability Annual Update [18]. The annual update did not include information regarding some of the seven points, and for these situations fictional data is used.

Several different visualizations may be used to respond to each of the seven points. Those shown in this section are a subset, however the visualizations presented are the ones most often used. Furthermore, interactive visualization has been identified as being effective to help decision-makers understand risks [19]. The visualizations discussed in this section could be implemented as interactive visualizations, however this aspect is not discussed since the software required to implement these features (e.g., D3, Tableau) may not be widely available on the defence organization's networks.

4.4.1 Assumptions, Bounds, Distributions, and Uncertainty

Any model is an abstraction of reality and, as such, assumptions have to be made to organize the analyst's thoughts. Within the context of risk analysis, the risk model helps the analyst to logically isolate and sort out complicated chains of cause and effect and influence between the numerous interacting risk factors. Certain cost risk assumptions may be dictated by the decision-makers while others by the analyst. Key assumptions are those that are most likely to significantly affect the determinations and/or estimates of risk presented in the risk analysis. The assumptions, therefore, need to be discussed in any costing study and the impact of implications if any of the assumptions do not hold or are relaxed. This reporting of assumptions can be done through the critiquing of the model (limitations) or through a discussion on why a given risk model or modelling strategy is chosen.

There are several methods to calculate contingencies or to provide a risk-adjusted cost estimate. The more popular and relatively established methods use probabilistic models either using the summation of various independent distributions (known as convolution) or simulations. Once again, it is useful to document and discuss why simulation or convolution is used in the risk analysis and the associated advantages and disadvantages of the chosen approach. Some of these discussions are necessarily complex. In such situations, the technical aspects should be relegated to an annex.

As a guiding principle, when reporting cost risk model assumptions, we suggest the following:

- Major model assumptions and the impact on the results, if incorrect. This can be relegated to an annex but needs to be part of the decision support document;
- Model strength and weaknesses;
- Rationale for picking the model given its strengths and weaknesses. This can be relegated to an annex;
- Model validation.
- Guide on how to interpret model results (particularly statistical and graphical outputs); and
- Data issues and problems; in particular, problems from the perspective of answering the decision questions and impacts on cost estimates.

4.4.2 Risks Associated with a Force Structure's Cost

The second point is to identify the risks associated with the project's cost. Table 4-1 shows the components of the Eppler and Aeschimann risk visualization framework and descriptions of how a visualization that shows the risks associated with a force structure's cost fit within the framework. The format description (i.e., last row in table) used is taken from Ref. [20].

Table 4-1: Risks Associated With a Force Structure's Cost Risk.

Risk Framework Component	Description
Purpose – why?	Framework/identification/assessment. To present the identified risks within the context of the risk framework.
Contents – what?	The risk framework and identified risks.
Group – for whom?	Executives.
Usage – when?	Costing study.
Format – how?	Table (graphical) / Graph.

A risk universe diagram may be used to convey the risks associated with a project's cost [17]. This visualization enables decision-makers to associate similar risks, since risks in each category are grouped together. The groups of risks are visually encoded, using position, which is the most effective encoding for categorical data (see Table 4A1-1 in Appendix 4-1). An example of a risk universe diagram is shown in Figure 4-6. The figure is interpreted as follows: There are ten categories[2] and a total of 37 relevant risks. In the figure, each risk is labelled as 'R_i', where i is a risk identification number, whereas in an actual implementation a short description of each risk would be provided.

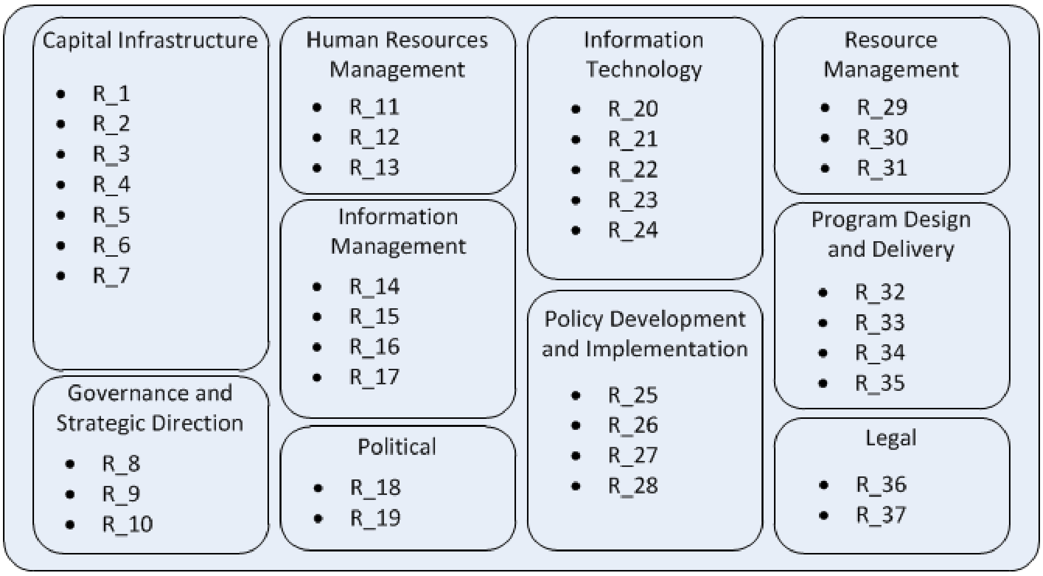

Figure 4-6: Risk Universe. Each category is represented by a rounded rectangle whose size is proportional to the number of risks identified in the category. Each risk is labelled as R_i, where i is the risk identification number.

A risk matrix may be used to convey the risks' likelihood and impact [19]. This visualization enables decision-makers to order risks by their likelihood and impact ratings. The risks are visually encoded using position, which is the most effective encoding for ordinal data (see Table 4A1-1 in Appendix 4-1), and their category is visually encoded using colour, which is the second most effective encoding for categorical data. Figure 4-7 shows an example risk matrix, where illustrative likelihood and impact used. The figure

[2] The categories are a subset of those listed in the Treasury Board of Canada Secretariat Guide to Risk Taxonomies. See https://www.canada.ca/en/treasury-board-secretariat/corporate/risk-management/taxonomies.html.

is interpreted as follows: Risk 4 is categorized as Capital Infrastructure with a likelihood of Likely and an impact of Major; Risk 21 is categorized as Information Technology with a likelihood of Almost Certain and an impact of Insignificant; etc.

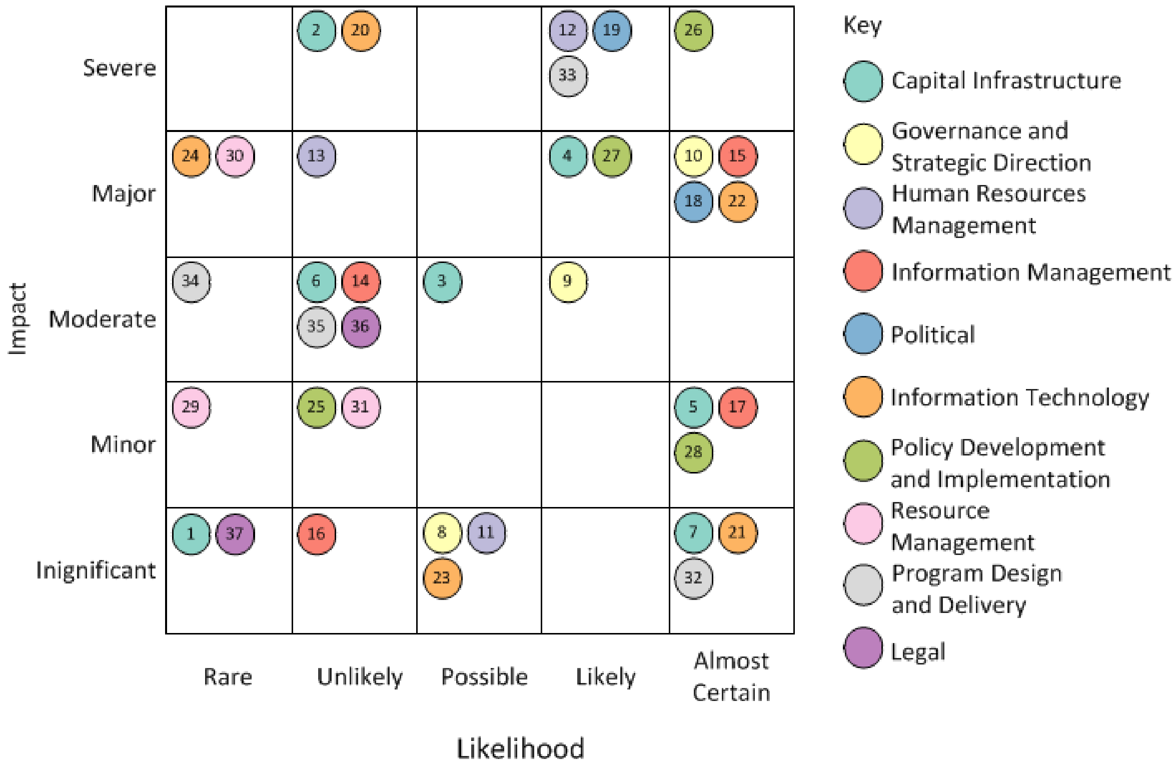

Figure 4-7: Risk Matrix. Each risk is represented by a circle, where i is the risk identification number and the circle's colour represents its category.

4.4.3 Sensitivity Analysis

The third point to be addressed is to provide a sensitivity analysis of the force structure's cost, including the scenarios that lead to the uncertainty. Table 4-2 shows the components of the Eppler and Aeschimann risk visualization framework and descriptions of how a visualization that shows a sensitivity analysis fits within the framework.

Table 4-2: Sensitivity Analysis.

Risk Framework Component	Description
Purpose – why?	To present the force structure cost's sensitivity within the cost/risk breakdown structure, and identify events that lead to uncertainty.
Contents – what?	Force structure's base cost and its sensitivity. The scenarios that are the cause of the high and low value of each category are listed.
Group – for whom?	Executives
Usage – when?	Costing study
Format – how?	Graph

A tornado diagram[3] may be used to convey the sensitivity of a project's cost (in budget year or constant year dollars) with respect to the cost/risk breakdown elements. This visualization enables decision-makers to understand the differences in the impacts of the uncertainty in the cost/risk breakdown elements. The breakdown elements are visually encoded using position (i.e., larger uncertainty near the top and smaller uncertainty near the bottom), which is the most effective encoding for categorical data (see Table 4A1-1 in Appendix 4-1). Furthermore, the uncertainty associated with each element is visually encoded using length, which is the second most effective encoding for quantitative data. Lastly, at the end of each bar appears a short description of the scenario associated with the high/low cost. An example of a tornado diagram is shown in Figure 4-8. The figure is interpreted as follows: a flyaway unit cost of $140 million is used to calculate the project's base estimate of $8.5 billion, a low flyaway unit cost of $110 million results in a base estimate of less than $7.5 billion, and a high flyaway unit cost of $180 million results in a base estimate of $9.75 billion.

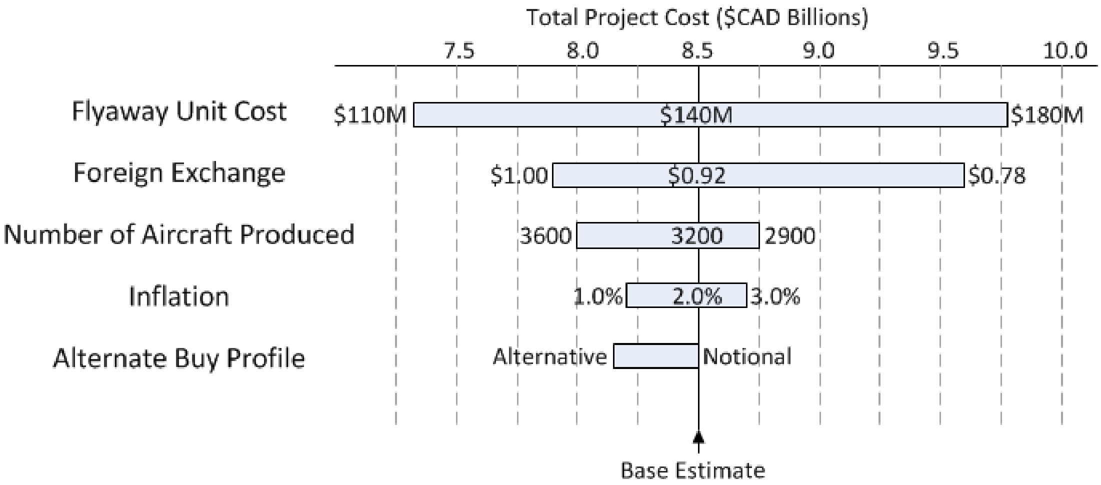

Figure 4-8: Sensitivity Analysis. Each category shows the base value used to calculate the project's base cost, and the low and high values in each category used to calculate the cost's sensitivity.

4.4.4 Correlation Between Risks

The fourth point to be addressed is the correlation between the identified cost/risk breakdown elements. Table 4-3 shows the components of the Eppler and Aeschimann risk visualization framework and descriptions of how a visualization of risk correlation fits within the framework.

Table 4-3: Correlation Between Identified Risks.

Risk Framework Component	Description
Purpose – why?	To present the correlation between the identified cost/risk breakdown elements.
Contents – what?	Cost/risk breakdown elements and their dependencies.
Group – for whom?	Executives.
Usage – when?	Costing study.
Format – how?	Chart (network) / Table (graphical).

[3] A tornado diagram is bar chart where categories are listed vertically, and the bars are sorted with the largest uncertainty at the top and smallest at the bottom [21].

An influence diagram may be used to convey if a positive or negative correlation exists between cost/risk breakdown elements. This visualization enables decision-makers to associate cost/risk breakdown elements, in terms of their relationships and correlations. The cost/risk breakdown elements are visually encoded using position, which is the most effective encoding for categorical data (see Table 4A1-1 in Appendix 4-1). The relationships between the breakdown elements are encoded using connections (lines), which is the simplest way of showing relationships [22]. An example of an influence diagram is shown in Figure 4-9. The figure is interpreted as follows: fuel price is influenced by inflation and foreign exchange, and in turn influences the yearly flying rate.

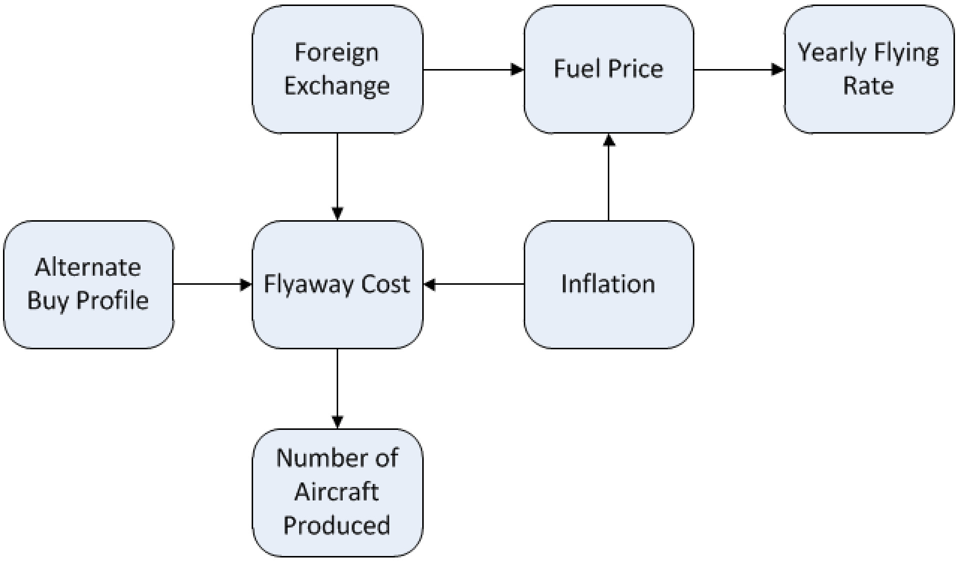

Figure 4-9: Influence Diagram. Breakdown elements are shown as rounded rectangles and relationships are shown as lines, where arrows indicate the direction of the relationship. For example, alternate buy profile influences the flyaway unit cost.

A heat map may be also be used to convey the strength of a correlation between the breakdown elements. This visualization enables a decision-maker to examine the breakdown elements and their correlation patterns. The elements are visually encoded using position, which is the most effective encoding for categorical data (see Table 4A1-1 in Appendix 4-1). The position of the elements may be determined by sorting the elements: highest to lowest single correlation, highest to lowest mean correlation, highest to lowest number of correlations, etc. The strength of the correlations is visually encoded using colour saturation, which is the one of the least effective encodings for quantitative data but the second most effective encoding for ordinal data. If a decision-maker focuses on the patterns of the correlations (e.g., Element *A* and *B* have a higher correlation than *A* and *C*) rather than the quantitative data, then a heat map is a good representation of correlations. An example of a heat map is shown in Figure 4-10. The figure is interpreted as follows: a positive correlation between 0.6 and 0.8 exists between foreign exchange and flyaway cost, and a negative correlation between -0.4 and -0.6 exists foreign exchange and fuel price.

4.4.5 Cost Distribution and Selected Contingency Level

The fifth and sixth points to be discussed are the force structure's base cost estimate, the probability of the base cost estimate, the distribution of the force structure's cost, and the selected contingency level. Table 4-4 shows the components of the Eppler and Aeschimann risk visualization framework and descriptions of how a visualization of the distribution of a force structure's costs fits within the framework.

A histogram, box plot, or cumulative distribution (S curve) may be used to convey the project's base cost estimate, its probability level, the distribution of the force structure's cost, and its contingency level. These visualizations enable a decision-maker to understand the difference between the base cost and contingency level. Each visualization is focused on communicating one of these items, but not both of them.

Figure 4-10: Heat Map. Breakdown elements are shown as columns and rows, and the correlation between elements is represented by colour; red is negative, and green is positive.

Table 4-4: Cost Distribution.

Risk Framework Component	Description
Purpose – why?	Assessment/strategy. To present the base cost, its probability level, the distribution of the cost, and the selected contingency level.
Contents – what?	Cost, distribution, and contingency level.
Group – for whom?	Executives.
Usage – when?	Costing study.
Format – how?	Graph.

In a histogram, the force structure's base cost and contingency level are encoded using position, which is the most effective encoding for quantitative data. The distribution of the project's cost is encoded using length, which is the second most effective encoding for quantitative data. While a histogram is a good visualization to show a force structure's base cost estimate and the distribution of the force structure's cost, it is difficult to understand the contingency level [23]. An example of a histogram is shown in Figure 4-11. The figure is interpreted as follows: the probability of the project's base estimate ($8.5 billion) occurring is 25\% and the selected contingency is $1.25 billion, giving a total project cost of $9.75 billion (red dashed line). However, the reason for selecting the contingency or its interpretation is difficult to understand.

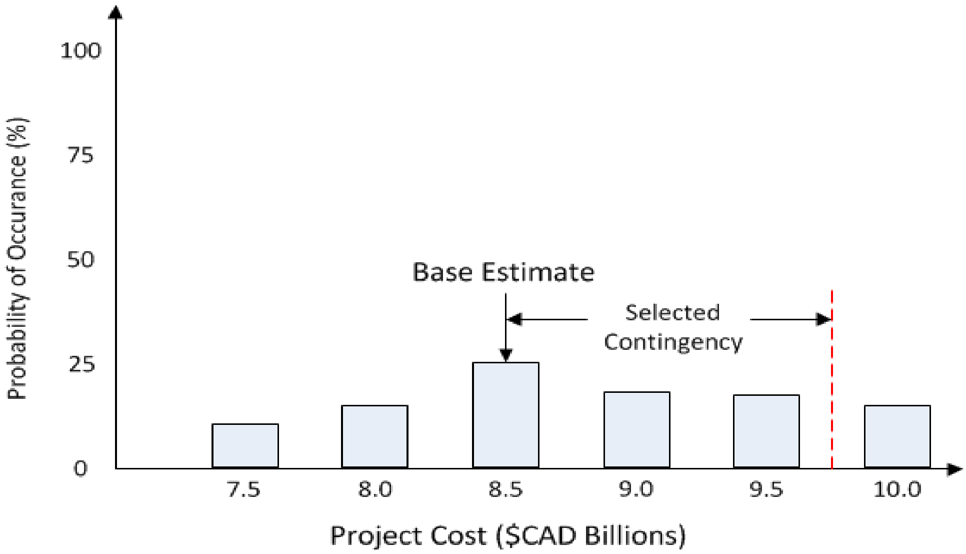

Figure 4-11: Histogram of a Project's Cost Distribution. The red dashed line represents the project's base cost estimate plus the selected contingency.

In a box plot, the force structure's base cost estimate and contingency level are encoded using position, which is the most effective encoding for quantitative data. While a box plot is a good visualization to show a force structure's base cost estimate and the distribution of the force structure's cost, it is difficult to understand the contingency level [23]. An example of a boxplot[4] is shown in Figure 4-12. The figure is interpreted as follows: the force structure's base estimate is $8.5 billion, and the selected contingency is $1.25 billion, giving a total force structure cost of $9.75 billion (red dashed line). However, the reason for selecting the contingency or its interpretation is difficult to understand. Furthermore, the probability of a specific force structure cost occurring is not immediately obvious.

In a cumulative distribution (S curve), the force structure's base cost estimate, distribution, and contingency level is encoded using position. While a cumulative distribution is a good visualization to show a force structure's base cost estimate and the contingency level, it is difficult to understand the distribution of the force structure's cost [23]. An example of an S curve is shown in Figure 4-13. The figure is interpreted as follows: the force structure's base estimate is $8.5 billion, and the selected contingency is $1.25 billion, giving a total force structure cost of $9.75 billion. The probability that the force structure's cost will not exceed the base estimate is approximately 50% and the probability that the force structure's cost will not

[4] A boxplot shows five measures for a distribution: lower whisker, first quartile, median, third quartile, and upper whisker. The lower and upper whiskers (horizontal lines outside the box) are the most extreme data points that are no more than 1.5 times the height of the box away from the box. The first quartile (bottom of the box) is the data point where 25\% of the distribution is lower. The third quartile (top of the box) is the data point where 25\% of the distribution is higher. The median (thick black line) is the data point where 50\% of the distribution is higher and 50\% of the distribution is lower. The data points outside the whiskers are outliers in the individual distributions.

exceed the base estimate plus contingency is approximately 95%. However, the probability of the base estimate occurring is not as clearly communicated as compared to the histogram and boxplot.

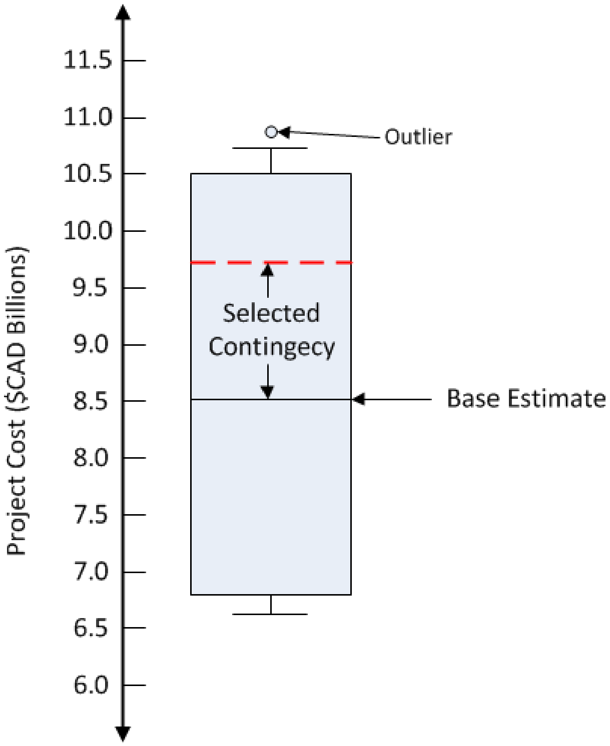

Figure 4-12: Boxplot of a Project's Cost Distribution. The solid black line is the project's base cost estimate and the red dashed line is the project's funding including selected contingency.

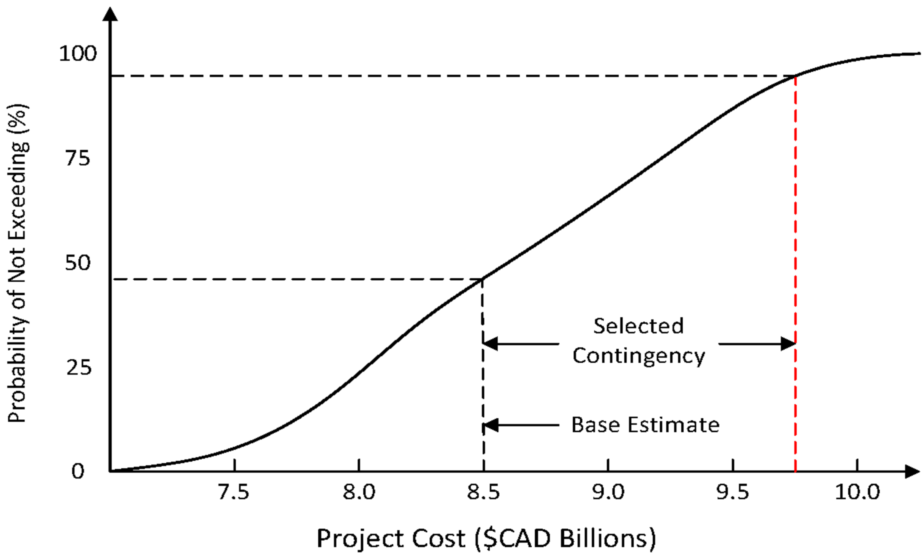

Figure 4-13: S Curve of a Project's Cost Distribution. The vertical dashed black line represents the project's base cost estimate and the red dashed line represents the selected funding level. The difference between these two values represents the selected contingency.

4.4.6 Cost By Year

The last point to be addressed is the risk-adjusted, in budget year dollars, force structure's cost by year to show phasing of risks. Table 4-5 shows the components of the Eppler and Aeschimann risk visualization framework and descriptions of how a visualization that shows a risk correlation fits within the framework [17].

Table 4-5: Eppler and Aeschimann Risk Visualization Framework.

Risk Framework Component	Description
Purpose – why?	Mitigation. To discuss the risk-adjusted, in budget year dollars, cost by year to show phasing of risks.
Contents – what?	Risk-adjusted cost, in budget year dollars, by year.
Group – for whom?	Executives.
Usage – when?	Costing study.
Format – how?	Graph.

A time series graph may be used to convey the project's risk-adjusted cost, in budget year dollars, over time (See Figure 4-14). This visualization enables a decision-maker to examine proportional differences between the year's risk-adjusted costs. The force structure's cost is visually encoded using position, which is the most effective encoding for quantitative data.

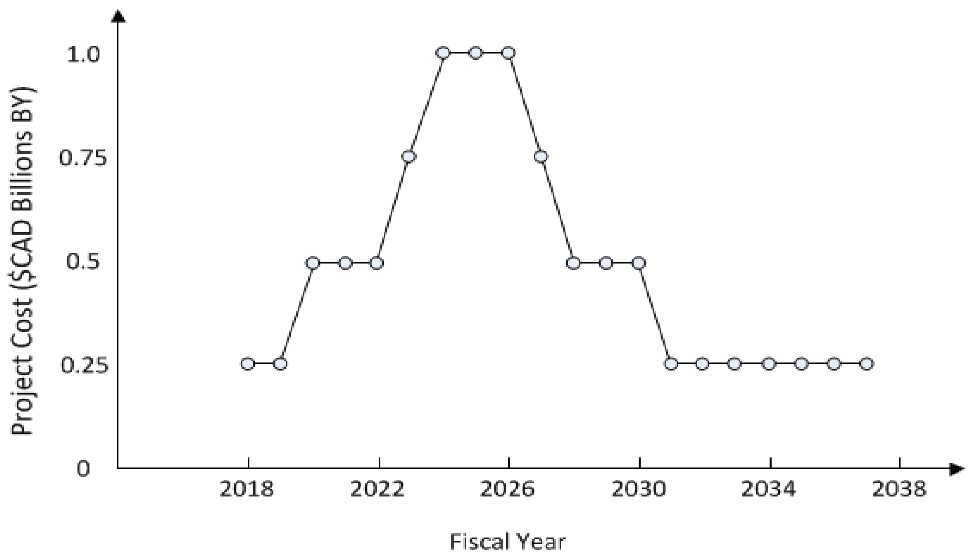

Figure 4-14: Time Series Graph of a Project's Risk-Adjusted Spending Profile In Budget Year Dollars.

4.5 CONCLUSION

In this chapter, visualizations to communicate cost risk analyses with decision-makers are presented and discussed. Seven topics related to a force structure's cost risk are identified that, if possible, should be included in a costing study. For each topic that can be addressed using visualization, example visualizations were presented. Each example was discussed in the context of a risk visualization framework and best practices to visually encode data.

The quality of the cost risk visualizations ultimately is determined by the ability of an analyst to turn the concepts discussed in this chapter into reality. Armed with the visualization guidelines and risk visualization framework, an analyst has the necessary tools to create simple and effective visualizations that ease the communication a force structure's cost risks with decision-makers.

4.6 REFERENCES

[1] Bier, V. (2001). On the state of the art: risk communication to decision-makers. *Reliability Engineering and System Safety, 71*(2), pp. 151-157.

[2] Rempel, M. (2014). Cost Risk Visualization, In *Cost Risk Framework* (pp. 61-100), Defence Research and Development Canada, DRDC-RDDC-2014-R167.

[3] Spiegelhalter, D., Pearson, M., and Short, I. (2011, September 9). Visualizing uncertainty about the future. *Science, 333*, pp. 1393-1400.

[4] Larkin, J., and Simon, H. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science, 11*(1), pp. 65-100.

[5] Tversky, B. (2005). Visuospatial Reasoning. In *Cambridge Handbook of Thinking and Reasoning* (pp. 209-240). Cambridge University Press.

[6] NATO RTO (2001). IST-013. *Visualisation of Massive Military Datasets: Human Factors, Applications, and Technologies.*

[7] NATO RTO (2009). SAS-069. *Code of Practice for Life Cycle Costing.*

[8] NATO RTO (2012). SAS-076. *NATO Independent Cost Estimating and the Role of Life Cycle Cost Analysis in Managing the Defence Enterprise.*

[9] United States Government Accountability Office (2009). *Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs.*

[10] Healy, C.G., and Enns, J.T. (2012). Attention and visual memory in visualization and computer graphics. *IEEE Transactions on Visualization and Computer Graphics, 18*(7), pp. 1170-1188.

[11] Bertin, J. (1983). *Semiology of Graphics.* University of Wisconsin Press.

[12] Cleveland, W.S., and McGill, R. (1985). Graphical perception and graphcal methods for analyzing scientific data. *Science, 4716*, pp. 828-833.

[13] Mackinlay, J. (1986). Automating the design of graphical presentations of relational information. *ACM Transaction on Graphics, 5*(2), pp. 110-141.

[14] Green, M. (1998). Towards a perceptual science of multidimensional data visualization: Bertin and beyond. *EROG/GERO Human Factors Science.*

[15] Tufte, E. (2001). *The Visual Display Of Quantitative Information.* Graphic Press.

[16] Kelleher, C., and Wagener, T. (2011). Short communication: Ten guidelines for effective data visualization in scientific publications. *Environmental Modelling Software, 26*(6), pp. 82-827.

[17] Eppler, M.J., and Aeschimann, M. (2009). *A Systematic Framework For Risk Visualization In Risk Management And Communication.* Institute for Corporate Communication. Vol. 11, No. 2 (Apr., 2009), pp. 67-89.

[18] Department of National Defence. (2013). *Next Generation Fighter Annual Update.* Ottawa.

[19] Roth, F. (2012). *Visualizing Risk: The Use of Graphical Elements in Risk Analysis and Communications.* Center for Security Studies. ETH Zurich.

[20] Lohse, G.L., Biolsi, K., Walker, N., and Rueter, H.H. (1994). A classification of visual representations. *Communications of the ACM, 37*(12), pp. 36-49.

[21] Vose, D. (2008). *Risk Analysis: A Quantitative Guide* (Third Ed.). San Francisco: John Wiley & Sons, Ltd.

[22] Spence, R. (2007). *Information Visualization: Design for Interaction* (2nd Ed.). Prentice Hall.

[23] Gresh, D., Deleris, L., and Gasparini, L. (2012). *Visualizing Risk.* IBM Research.

[24] Ware, C. (2013). *Information Visualization: Perception for design* (3rd Ed.). Amsterdam: Elsevier.

Appendix 4-1: VISUALIZATION GUIDELINES

4A1.1 PRE-ATTENTIVE VISION

The selection of how data is visually encoded strongly affects a visualization's ability to ease communication of information with decision-makers. Good visual encodings are those that take advantage of how human vision works, in particular how it can rapidly assess images. This rapid assessment is referred to as pre-attentive vision [10]. Pre-attentive vision is so important to visualization that Ware (2013) wrote:

> "An understanding of what is processed pre-attentively is probably the most important contribution that visual science can make to data visualization" [24].

In general, pre-attentive vision involves visual features that can be detected by the human visual system without focusing attention on particular regions in an image. For example, tasks, such as identifying an object, which can be performed in 200–250 milliseconds are considered pre-attentive. To perform such a quick assessment the target object must be defined by a unique visual property (e.g., orientation, length, size, etc.). Objects that are defined by two or more visual properties typically cannot be detected pre-attentively. Although there are several theories that attempt to explain pre-attentive vision (e.g., Feature Integration Theory, Texton Theory, Similarity Theory, etc.), they usually agree on which visual encodings we can attend to. Figure 4A1-1 shows examples of pre-attentive visual encodings.

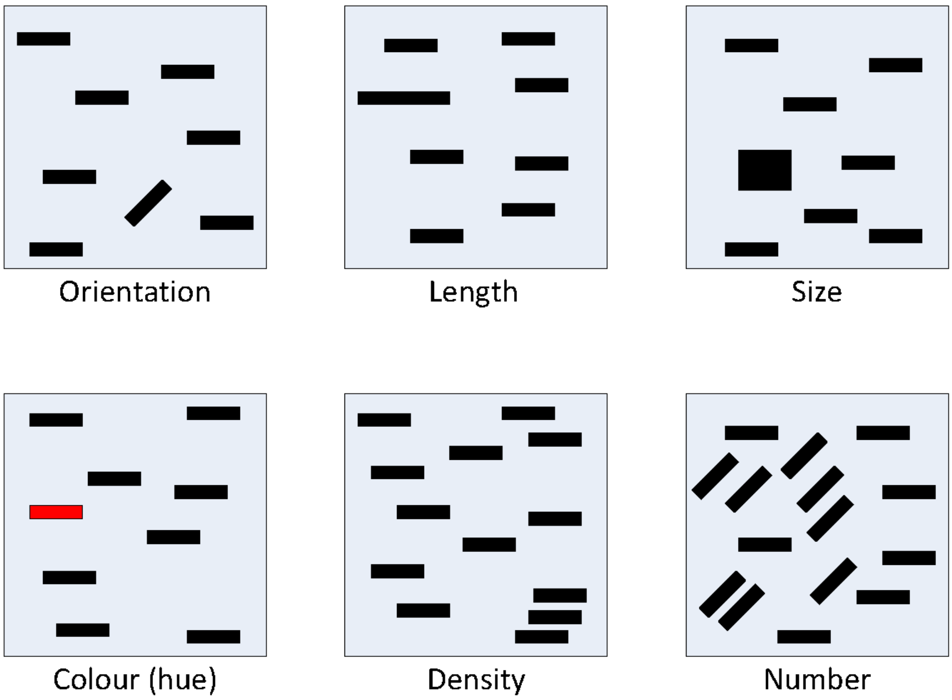

Figure 4A1-1: Examples of Pre-Attentive Visual Encodings.

4A1.2 VISUALLY ENCODING DATA

With this knowledge of pre-attentive vision, guidance has been developed on how to best to use visual encodings to represent data. Four sources that are often cited are Bertin, Cleveland and McGill, Mackinlay, and Green [11], [12], [13], [14]. The work of Bertin and Green focused on identifying visual encodings that lead to good quality visualizations. Bertin made two important contributions. First, Bertin identified four tasks that are common to information visualization. Two of these are about perceiving encodings as similar (association) or different (selection), perceiving encodings as ordered (order) or proportional to each other (quantity). Second, Bertin suggested six visual encodings that can be used to help individuals perform these tasks: size, value, texture, colour, orientation and shape. Bertin ordered these roughly according to the number of tasks that each encoding could support, as shown in Figure 4A1-2.

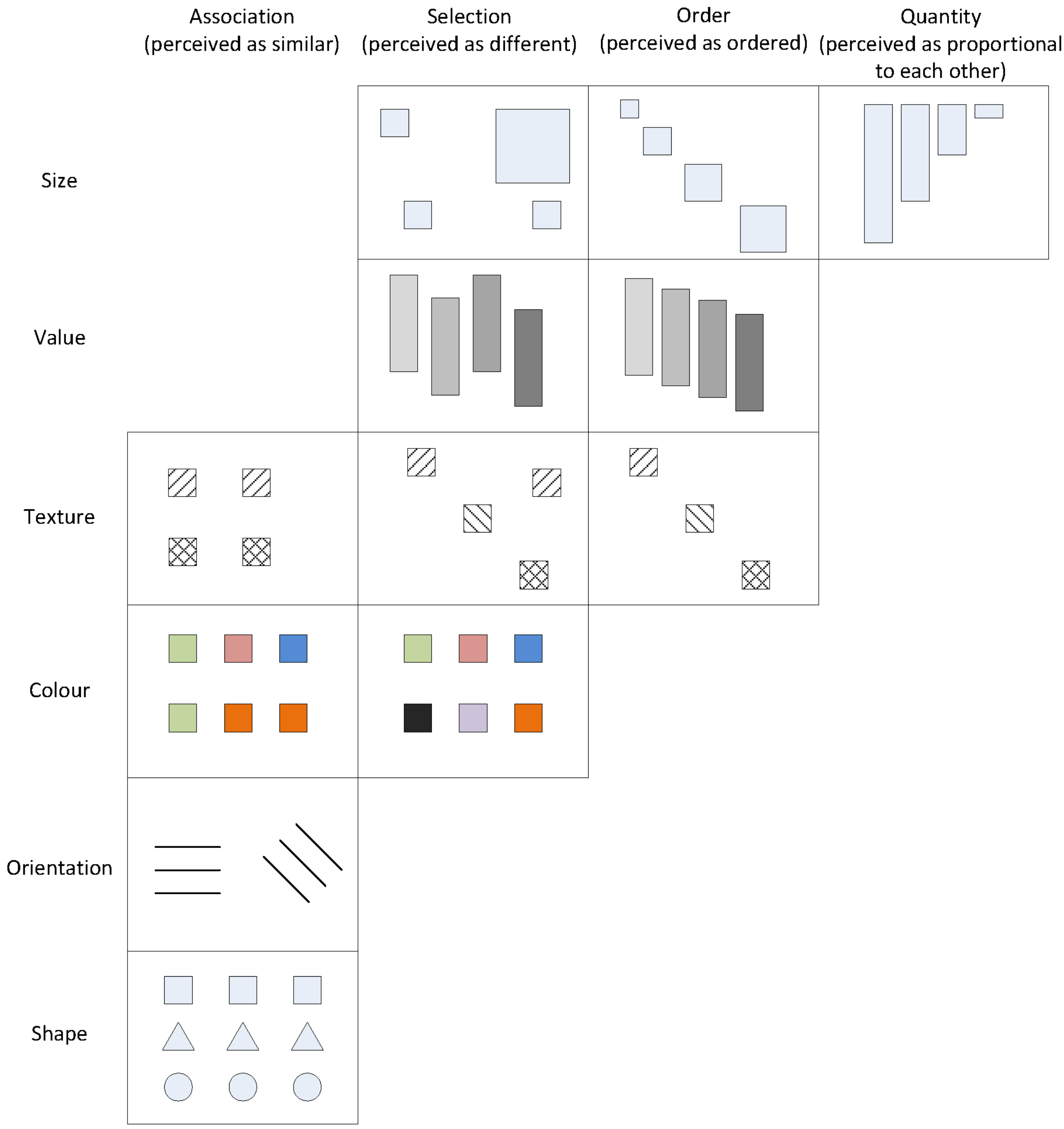

Figure 4A1-2: Suitability of Various Visual Encodings to Support Common Information Visualization Tasks as Proposed by Bertin [11].

Green argued that Bertin's work, which was developed for visualization on a printed page, was neither complete nor entirely accurate and that dynamic visualization should be included. One example of dynamic visualization is the use of motion or velocity as an encoding for selection, ordering and quality. The suitability of various encodings as suggested by Green are listed in Table 4A1-1.

Table 4A1-1: Suitability of Various Visual Encodings in Information Visualization as Proposed by Green [14].

	Association	Selection	Order	Quantity
Planar	Yes	Yes	Yes	Yes
Style		Yes	Yes	Yes
Brightness		Yes	Yes	Yes – if scaled
Texture	Yes	Yes	Yes	
Colour (hue)	Yes	Yes	Yes (limited)	
Orientation	Yes	Yes		
Shape	Yes	Yes		
Motion (velocity)		Yes	Yes	Yes – if scaled
Motion (direction)		Yes		
Flicker (frequency)		Yes	Yes	Yes – if scaled
Flicker (phase)		Yes		
Disparity		Yes	Yes	

The resulting differences between Green and Bertin visual encoding assignments can be divided into two groups: changes to Bertin encodings and additional encodings. Changes in Bertin encodings by Green are:

- Shape can be selective. Green points out that several studies show that a large number of shapes can be selective and/or associative, and that Burton did not identify shapes as selective due to a very narrow definition of shape used in his work;
- Colour can be ordered. Green points out that over a small range hue[5] can be ordered (e.g., an ordered scale of yellow-green continuum). For example, the Farnsworth-Munsell Test[6], a commonly used test for colour blindness, asks individuals to order tiles base on their hue; and
- Brightness is ordered, but it is only sometimes quantitative. This is because brightness results in a psychometric function (i.e., relationship between a physical stimulus intensity and a perceived magnitude) that is nonlinear (i.e., perceived magnitude grows more slowly than physical intensity). However, if brightness is correctly scaled such that a doubling in brightness results in a doubling in perceived magnitude, then it may be quantitative. It must be noted that brightness can be used in such a manner on a computer screen, not in print.

Meanwhile, additional encodings identified are:

- Motion (velocity) can be used for selection, ordering, and quantity. Green points out that:
  - Several studies have shown pre-attentive search based on motion differences;

[5] Colour hue defines pure colour (i.e., red, green, blue). Colour saturation defines a range from pure colour (i.e., from pure colour to gray) at a constant lightness level. The website ColorBrewer (http://colorbrewer2.org/) may be used to select colour schemes.

[6] See http://www.color-blindness.com/farnsworth-munsell-100-hue-color-vision-test/.

- Velocity is likely to be ordered, since it is a continuum of magnitude and it is relatively simple to discriminate steps of increasing value; and
- Velocity is typically not quantitative since it produces a nonlinear psychometric function, however appropriate scaling can compensate for this.

- Motion (direction) can be used for selection.

Cleveland performed experiments to assess the relationship between visual encodings and how well an individual could assess quantitative data (i.e., data that can be measured numerically). The study results show that, among others, position along an axis is a preferred encoding over length, which is preferred over angle [12]. The least favoured encodings are colour and density. Figure 4A1-3 shows the Cleveland and McGill study results, which are ordered with most accurate at the top and least accurate at the bottom.

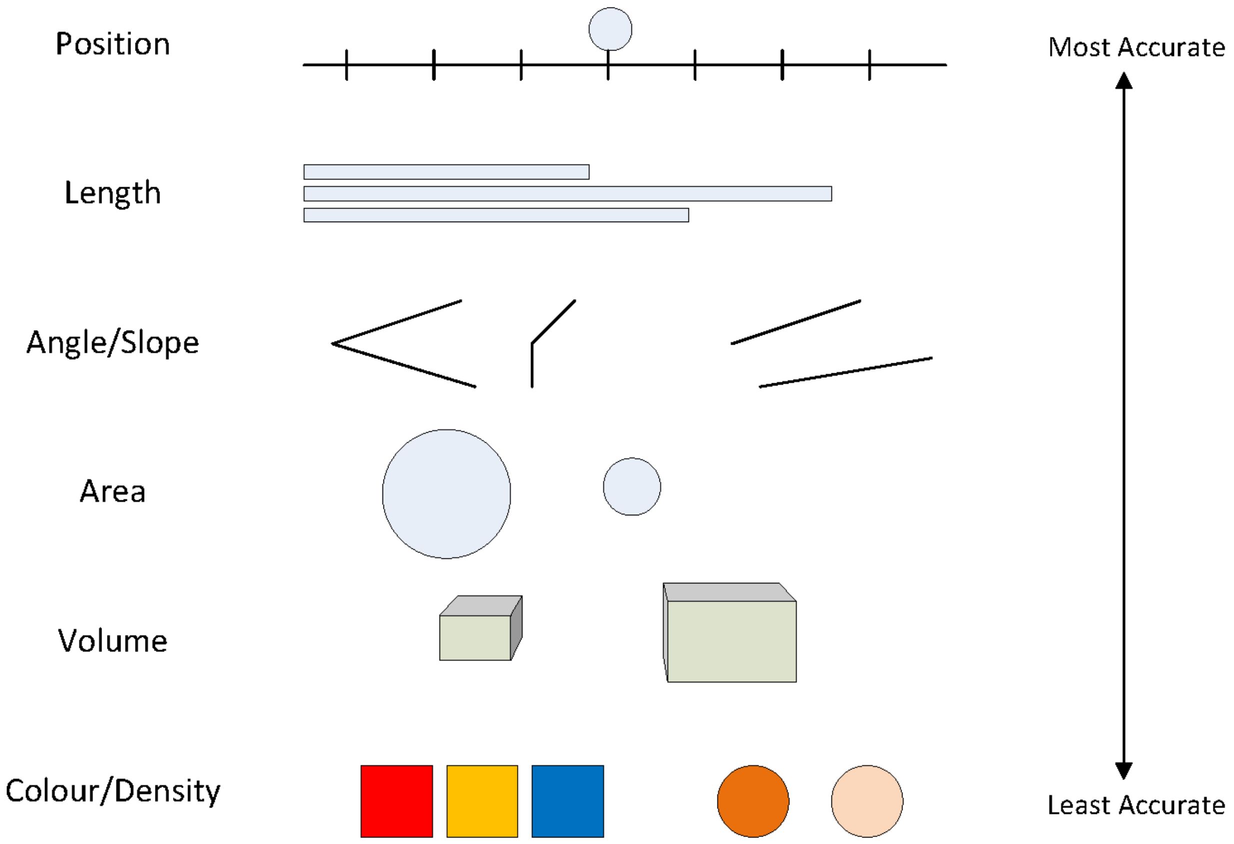

Figure 4A1-3: Relative Difficulty of Assessing Quantitative Value as a Function of Visual Encoding as Suggested by Cleveland and McGill. Most accurate encodings are at the top and least accurate are at the bottom.

Similarly, Mackinlay studied visually encoding quantitative and non-quantitative data. He created rankings of visual encodings for quantitative, ordinal data (i.e., arbitrary numerical scale where values have no significance beyond the ability to establish a ranking), and categorical data (i.e., data that cannot assume a numerical value but can be classified into two or more nonnumeric categories) [17]. The results are shown in Table 4A1-2 with the most accurate encodings at the top of the table and the least accurate encodings at the bottom of the table. As an example, for categorical data position is preferred over colour, which in turn is preferred over texture.

Table 4A1-2: Relative Difficulty of Assessing Quantitative, Ordinal, and Categorical Data, as Suggested by Mackinlay.

Quantitative	Ordinal	Categorical
Position	Position	Position
Length	Density	Colour hue
Angle	Colour saturation	Texture
Slope	Colour hue	Connection
Area	Texture	Containment
Volume	Connection	Density
Density	Containment	Colour saturation
Shape	Length	Shape
	Angle	Length
	Slope	Angle
	Area	Slope
	Volume	Area
		Volume

4A1.3 GENERAL VISUALIZATION GUIDELINES

In addition to guidelines on how best to visually encode data, general guidelines have been developed to support the design of good visualizations. Though several references exist, two that are often cited are Tufte and Ware [15], [24]. Tufte described general guidelines for graphic excellence and integrity that lead to good visualizations. In order to create graphic excellence, he suggested:

- Show the data;
- Induce the viewer to think about the substance rather than the methodology;
- Avoid distorting data (e.g., three-dimensional pie charts can lead to poor interpretation due to perspective);
- Present a large amount of data in a small space[7];
- Make large data sets coherent;
- Encourage the eye to compare data;
- Reveal the data set at several levels of detail;
- Serve a clear purpose: description, exploration, tabulation, or decoration; and
- Closely integrate statistical and text descriptions.

In order to create graphic integrity, avoid deception, and avoid misrepresentation of data he provided six guidelines:

- Graphic presentations related to numbers should be directly proportional to the quantities represented;

[7] The goal of this suggestion is to create visualizations that allow individuals to understand a large amount of data at a glance; that is, communicate a story as effectively and efficiently as possible.

- Clear and detailed text should be used whenever needed to avoid ambiguity;
- Show data variation and not design variation;
- Money in time series should be adjusted for inflation;
- The number of dimensions used for reading data should not exceed the number of data dimensions being represented; and
- Do not show data out of context.

Ware wrote a comprehensive book on information visualization that includes many theories on visual perception and comprehension [24]. The book emphasizes cognitive psychology and physiological research rather than practical grounded research like Tufte's. Ware offers over 150 practical guidelines (e.g., design graphic representations by taking into account human sensory capabilities, important data elements should be represented by graphical elements that are more visually distinct) to support the design of visualizations. These are too numerous to list here; Kelleher suggested ten guidelines, based on Tufte, Ware, and several other researchers, to inform the design of data visualizations in scientific publications [16]. These guidelines are:

- Create the simplest graph that conveys the information you want to convey;
- Consider the type of encoding object and attribute used to create a plot;
- Focus on visualizing patterns or on visualizing details, depending on the purpose of the plot;
- Select meaningful axis ranges;
- Data transformation and carefully chosen aspect ratios can be used to emphasize rates of change for time series data;
- Plot overlapping points in a way that density differences become apparent in scatter plots;
- Use lines when connecting sequential data in time series plots;
- Aggregate larger datasets in meaningful ways;
- Keep axis ranges as similar as possible to compare variables; and
- Select an appropriate colour scheme based on the type of data.

Several sources use these guidelines to provide advice for commonly used chart types. For example, Gary Klauss from Illinois State University summarized rules for pie, bar, time series (line) and scatterplots. The rules are:

- **Pie charts**
  - Avoid using pie charts
  - Use pie charts only for data that adds up to something meaningful.
  - Never use three-dimensional pie charts.
  - Avoid forcing comparisons across more than one pie chart.
- **Bar**
  - Do not use three-dimensional effects.
  - Set the reference to zero.
  - Sort the data on the most significant variable.

  - Use rotated bar charts if there are more than eight to ten categories.
  - Place legends inside or below the plot area.
  - With more than one data series, beware of scaling distortions (i.e., numbers of different magnitudes).
- **Time series (line)**
  - Time is almost always displayed on the x-axis from left to right.
  - Make sure the reader can distinguish between the lines for separate data series.
  - Beware of scaling effects.
  - When displaying monetary data over time, it is often best to use deflated data.
- **Scatterplot**
  - Use two interval-level variables (i.e., difference between two values is meaningful).
  - Fully define the variables with the axis titles.
  - The chart title should identify the two variables and the cases.
  - Place the independent variable on the x-axis and the dependent variable on the y-axis.
  - Scale the axes to minimize the plot area for displaying the data points.
  - Add data labels to identify cases.

Chapter 5 – DEFENCE SPECIFIC INFLATION AND COST ESCALATION

5.1 INTRODUCTION

This chapter deals with defence specific inflation (DSI) and defence specific cost escalation (DSCE). The terms DSI/DSCE are explained and the reasons to why DSI and DSCE occur are discussed as are their consequences for planning and decision-making.

The chapter is partly built on an article in Defence and Peace Economics written by a NATO SAS-092 member [1].

Models for costing and cost calculations of future force structures have to cope with the future price and cost levels for resources needed in defence. In this NATO-SAS group, we have studied the cost models for force costing and the risks and insecurities in long term force planning. The context is illustrated in Figure 5-1.

The modelling and calculations have to deal with questions such as:

- How do we cope with DSI/DSCE in our cost models and cost calculations?
- How do we expect that DSI/DSCE will influence future decisions on the defence budget?
- What risks and insecurities does DSI/DSCE imply?
- Should we take DSI/DSCE into consideration when actually designing, constructing and composing a future force structure? Could DSI/DSCE influence the future choices of resource mixes?

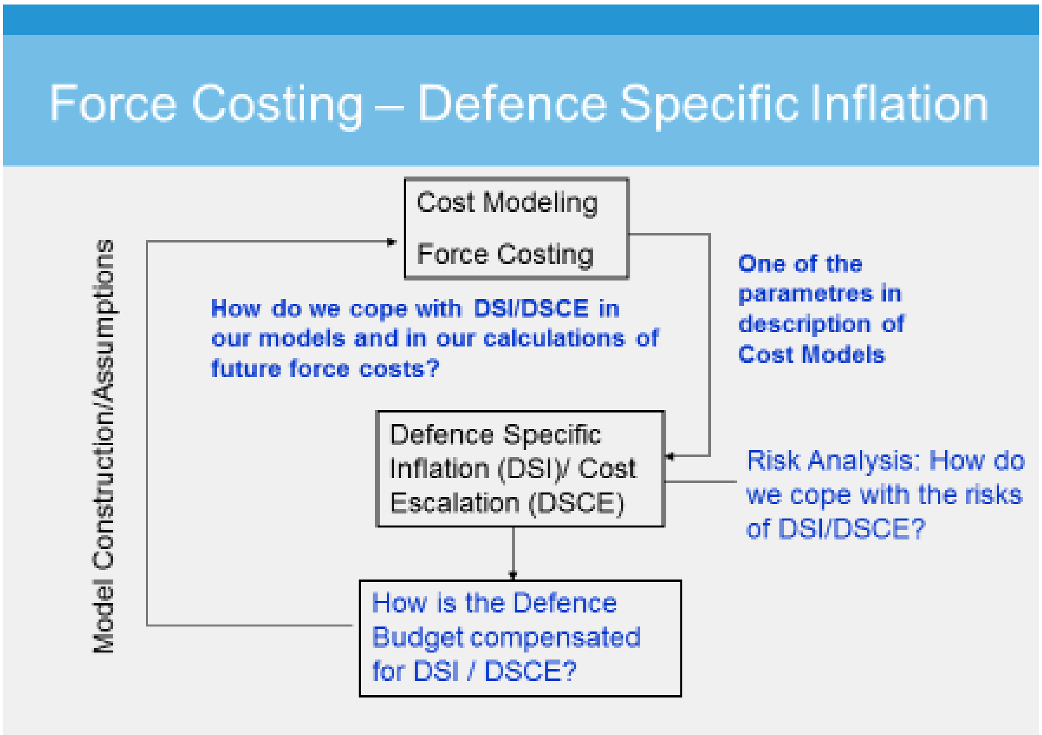

Figure 5-1: Context with Force Costing Models and Calculations.

The price and cost development for the resources needed in defence are likely to deviate from general inflation and cost evolvement which is referred to as defence specific inflation or defence specific cost escalation. Normally defence specific inflation is defined as the difference to the Consumer Price Index (CPI) and/or in some cases the GDP-deflator.

It is common practice in Sweden to compare with the so-called Defence Price Index (FPI).

FPI is a composite index made up by different official and non-military indices that are supposed to compensate the Swedish Armed Forces for inflation. The composition of FPI should both reflect the resource mix of the Swedish Armed Forces and the price changes of these resources. A new base for the decision of the level of the budget for the next year is calculated by adjusting the last year's budget with FPI. This base level is the level from which the political decisions are made and the corresponding effects on the budget of these decisions are calculated. This means that next year's budget is a result of an "automatic" calculation to compensate for inflation and intentional, explicit political decisions and their estimated effect on the budget almost on an incremental basis ("What do we do next year that we did not do this year?").

Most studies (e.g., Refs. [2], [3], [4], [5]) point to defence specific inflation in general, and defence specific cost escalation in particular (explained later), tends to exceed general inflation.

International comparisons of defence budgets over the years, those from SIPRI, are made by using consumer price indices to compare the budgets over time in real, inflation adjusted, terms. But since the inflation of defence resources are likely to deviate from CPI this is a rough estimate that tends to overestimate the purchasing power of the defence. But since most countries calculate a CPI with a rather comparable method there are no easy alternatives to CPI for wide international comparisons. Some countries calculate a defence price index based on general indices as approximates for defence, so-called proxy indices. Even fewer calculates the actual price development of the specific resources used by defence.

The existence of a higher inflation and cost escalation in the defence sector compared to general inflation tests the politicians, as representatives for the citizens, willingness to pay for the defence and its higher price and cost evolvement.

In periods of high threat levels and great tension the willingness to pay a higher "insurance fee" for national and international security can be present. However, under normal conditions the defence has to plan for reduced volumes due to the higher price and cost evolvement in defence.

This tendency is observed by Norman Augustine [6] in one of his so-called "laws":

> *"In the year 2054, the entire defense budget will purchase just one aircraft. The aircraft will have to be shared by the Air Force and Navy 3 ½ days per week except for leap year, when it will be made available to the Marines for the extra day".*

The lower volumes are, at least to some extent, compensated with gradually higher performance from each unit of the weapon systems. This will be elaborated further in this chapter.

5.1.1 Key Terms

It is important to make a distinction between escalation in price (inflation) and cost escalation. They are not synonymous terms. This difference is of particular importance with respect to defence equipment. In addition to "pure" price movements the unit costs of defence equipment can escalate due to higher performance and capability.

Technological developments are driving more advanced, but more expensive weapons systems. This occurs mainly in connection with generational changes for equipment where the new generation has both higher performance and often substantially higher unit costs. Cost escalation means that the cost per unit of a product changes as a result of both price effects and changes in quality of a product.

A price index aims to measure price changes of an unchanged or similar good or service. Price indices are normally adjusted for changes in quality, performance and capability. This means that the cost changes need to be divided into a pure price changes and an effect of changes in quality and capability (see Figure 5-2).

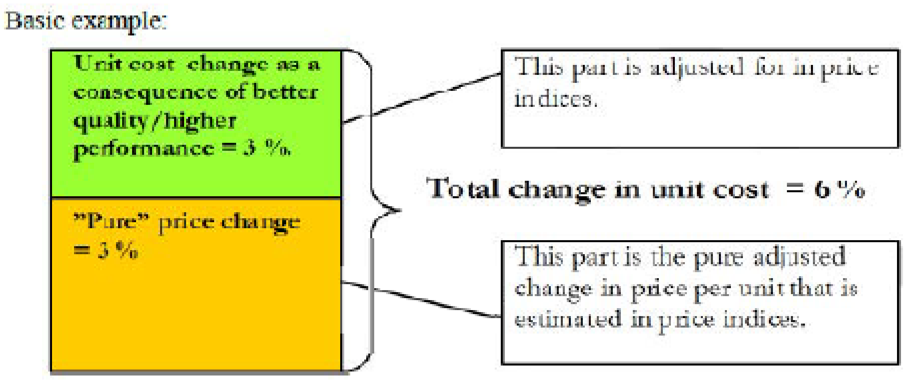

Figure 5-2: Price and Cost Escalation.

The difference between pure price movements ("inflation") and cost is highly valid for the defence in general and for defence equipment in particular. The cost trend is high and often considerably higher than the more general price indices such as the CPI. But it does not have to mean that the pure price movements have been as high.

It is also important to distinguish between inflation/cost escalation and high price levels. Inflation/cost escalation measures the change in price/costs over time whereas high price level means that the present prices are high compared with other goods, services and sectors.

5.1.2 Theoretical Background and Reflections

Output *vs.* Input

Normally inflation is measured for the end product. In defence, that would be the output in terms of total defence effect, total defence capability or other end results of activities within defence. It is very difficult, some claim impossible [7], to measure defence output in a standardized, quantitative way. Trying to measure the price of "one standardized unit of defence capability" over years and thus establishing defence specific inflation or defence specific cost escalation in output terms has proven to be too tough as a challenge.

Defence specific inflation/cost escalation is thus measured on the basis of different inputs in producing the "immeasurable output". The price and cost evolvement of different resources are the bases for defining and measuring DSI/DSCE. The most important resources being defence equipment and personnel. In later parts of this chapter we will reflect on DSI/DSCE for these resources.

In the National Accounts and as measured in Gross Domestic Product the output of defence is defined as the sum of costs for the resources used in the production, i.e., the defence output equals the costs of inputs.

5.1.3 The Theory of Price Formation

To understand how price differences can arise between the defence and other sectors of society the theory of price formation can be a starting point. This part describes the theory and the reasons why the price formation for defence may be different than for other sectors of society.

The price of a good or a service in a market is determined by supply and demand. We continue to use the term "good" as a generic term for both goods and services. The demand for a good increases, the lower the price is. The cheaper the product, the more consumers will ask for the goods. If we draw this relationship in a chart that indicates the price of the item on the vertical axis (y-axis) and the quantity of the goods on the horizontal axis (x-axis), we get the so-called demand curve (see Figure 5-3 below, we have simplicity, assuming a linear relationship between the price and the quantity demanded).

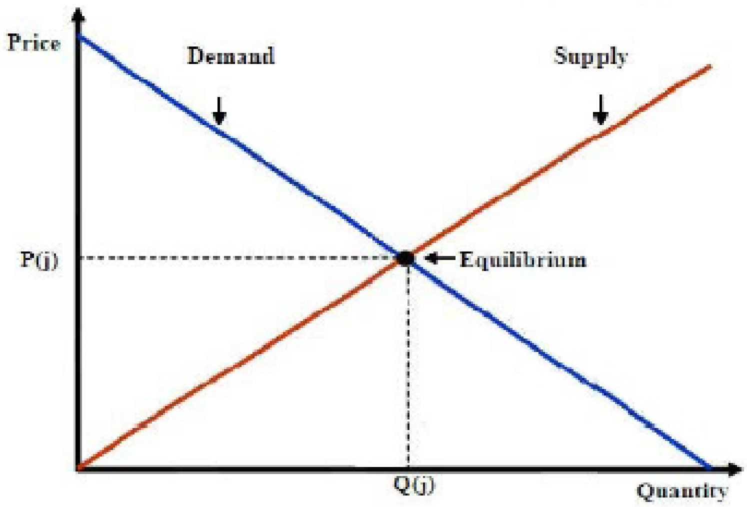

Figure 5-3: Demand and Supply Curve.

The supply of goods will, however, show an inverse relationship. Supply increases the higher the price is. The more you get paid for your goods, the more interest in producing the goods. This is reflected in the so-called supply curve (see Figure 5-3). Consumers and producers thus have different interests reflected the opposite interest in the relationship between price and quantity (see the Figure 5-3). In a "perfect market", in the market so-called equilibrium point where consumers and producers at the same price ask for / offer the same quantity. At this point, the market is in balance. This point corresponds to the price P (j) and the quantity Q (j) of FIG. The price of the product is thus P (j) and the quantity sold Q (j).

Changing market conditions, changes in sales taxes and commodity subsidies may affect demand or supply conditions. It is customary to speak of so-called shifts in demand or supply curve (see Figure 5-4). A sales tax on the goods in question paid by the consumer affect demand negatively by a shift in demand, which means that a smaller quantity than before will be demanded at each price level. We get a new one, shifted the demand curve and as a consequence a new equilibrium at a new lower price P (s) and a lower quantity Q (s).

Similarly, changes in the conditions of the market cause shifts in both demand and supply curves.

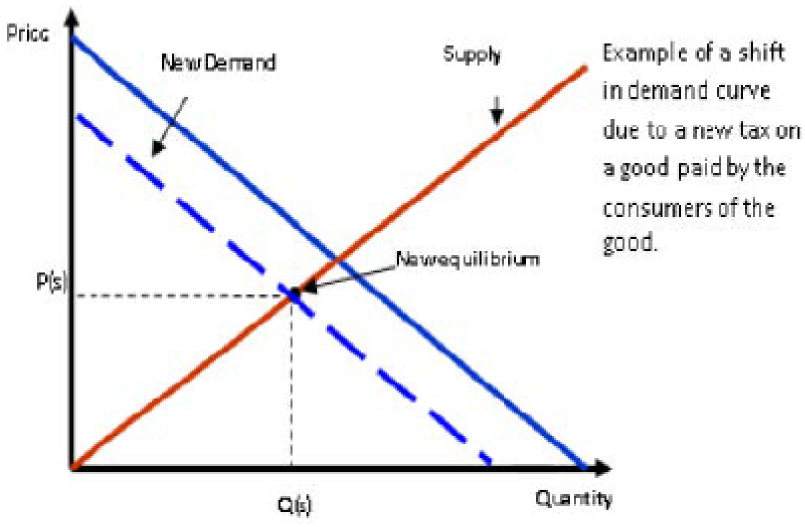

Figure 5-4: Shifts in the Supply-and-Demand Curve.

In a "perfect market", no excess profits will exist in the long term. In the short term, companies can make excess profits in an industry where demand is rising, which then means that the price of the good will rise. In the longer term, attracted by profits, however, new companies want to start producing the goods, and the supply curve is changed so that an equilibrium occurs with a price and a quantity where no excess profits arise.

A "perfect market" must fulfil requirements for so-called "perfect competition" which means:

- All market players have perfect (i.e., all relevant) information;
- No transaction costs exist;
- Freedom of establishment on the market;
- No cartels nor among consumers or producers;
- The goods are uniform/homogeneous (i.e., equivalent goods to be found at many retailers);
- There are many sellers and buyers;
- No monopoly exists; and
- There are no economies of scale.

This means that both consumers and producers are "price takers", which means that not one of them can affect the price. They have to "take", or accept, the price set by the market. Perfect competition is achieved very rarely, and most markets are characterized by so-called market imperfections, which means that one or more of the conditions for a perfect market is not met. Price formation in such markets will be different. This does not mean that the theory of price formation as a price level that balances supply and demand often have one, if not entirely, explanatory value, even where various market imperfections exist.

Other market and competitive conditions affect the way in which prices and quantities are determined on different markets. Other competitive situations are:

- *Monopoly* is a market situation where there is only one company that sells/produces one or more products at the same time as there are many buyers. A monopoly arises when there are barriers to entry on the market. The only company in a monopoly market can affect production volumes and prices on its own. A market with a monopoly has higher prices than a market where perfect competition exists. Legal monopolies arise from patents and other legal causes. Natural monopolies occur where a company, through economies of scale, can make the whole market at a lower price than if there were more companies.

- *Oligopoly* is a market form with a few companies who produce/sell their goods to many buyers. In an oligopoly, any company can affect the market price. Oligopoly is characterized by companies following any price change that any of the few competitors to take. Oligopoly means higher prices for consumers compared to a perfect market, but lower prices compared to a market where a monopoly exists.
- *Monopsony* is buyer-side's equivalent to monopoly. At monopsony, there is only one buyer in the market but several companies providing goods. The only buyer can then determine quantity with a great influence on the price. The result will be a lower quantity and a price lower than in a perfect market.
- *Bilateral monopoly* is a market situation with only one seller and one buyer, i.e., monopoly and monopsony simultaneously. In this situation the price is instead the result of a negotiations where the strength of the two parts are decisive for the outcome in terms of price and volume.

There are also additional variations on market conditions but the above mentioned are sufficient to illustrate that the price formation is affected by the market conditions.

Price of a commodity is also affected if the price changes of other products which are related to the product in question. These relationships may mean that other goods are so-called substitutes for the product. Substitutes are other goods that consumers consider able to replace the product in question. If the price of a substitute is going up or down creates price pressure in the same direction for the product in question. Through the so-called *substitution possibilities*, consumers can limit the effect of price increases. If the price of a good goes up and there are substitutes, consumers increasingly buy substitutes and thus completely or partially avoid the effect of the price increase. Good substitution opportunities for goods and services for a consumer is therefore important to be able to adapt to and limit the effect of price increases.

Another relation between goods could be that the product in question has other goods which are considered as complements. For example, for an inkjet printer, the ink cartridges are complementary products. An increase in the price of a complementary product has a negative effect on the demand for that commodity. If the price of a complement goes up or down, it creates price pressures in the opposite direction for the product in question by the price of that product can make up for the price increases of complementary goods.

5.2 DEFENCE AS A PRODUCT AND WHY THERE IS DEFENCE SPECIFIC INFLATION

5.2.1 The Product "Defence"

Most studies suggest that "Defence" acts like a "normal good" meaning that demand for defence probably increases with lower price levels and falls with higher price levels. A faster price evolvement for defence (DSI) will consequently tend to make politicians less willing to pay for an increased volume of defence. But defence is also a "collective good" shared by everyone in a nation, which makes too strong market analogies problematic.

Defence is also a "normal good" in the sense that we demand more defence with higher income. Most studies show a positive correlation between defence expenditures and GDP. Though the correlation is positive, defence expenditures rises with higher GDP but not as fast. This means that the defence expenditures as a share of GDP shows declining tendencies in most countries. The slower growth in defence expenditures with higher GDP suggests that defence is not what is referred to as a "luxury good".

5.2.2 Causes for Defence Specific Inflation

Why is there Defence Specific Inflation? There are a number of reasons to DSI [5]:

1) Defence uses other resources, and often rather unique resources, than those of other consumers. Specialized unique products such as defence equipment are not, luckily so, very common among private consumers. The defence's mix of goods and services are different than the underlying mix that constitutes the general price indices, such as the Consumer Price Index (CPI).
2) The market situation for defence resources is often different from those on other markets. Imperfect conditions in some segments of the market may create a potential for significant price fluctuations in the goods and services that the defence consumes than elsewhere in the economy. For instance, defence equipment, are often found in markets characterized by monopoly, oligopoly, monopsony or bilateral monopoly and seldom in markets with a high level of competition. Some of the more distinctive characteristics of military goods and services, which affect market conditions, are:
   a) A unique relationship between buyer and seller;
   b) Political regulations regarding foreign material and influence as well as grounds of national security;
   c) "Rent seeking" behaviours of the defence industry and other parties using military spending for purposes other than security – such as industrial and regional support; and
   d) Slowing economies of scale in defence related to the technological development can create a level of inflation that is different from the rest of the economy.
3) Fluctuations in exchange rates will have a greater impact on defence than other parts of the market when defence consumption usually acts as a direct final consumption. This leads to inflation in this part of the market, while the same phenomenon in the economy, as a whole, tends to be tempered by other factors.
4) The substitution possibilities are more limited in the defence sector than most other sectors of the economy. This means that it is more difficult for defence to adapt by finding substituting resources for the resources that have had fast rising price levels.

5.2.3 The Defence as a Product – Relative Effect or Absolute Effect

For the reasons described and illustrated above, it is important to distinguish between defence specific inflation and defence specific cost escalation. In defence specific costs there are also effects on unit costs, which arise from increased demands for better capability of the resources defence uses in its operations, included. For most other products, it is the absolute effect of the product that is interesting: a consumer can unreservedly be happy about a safer car, a television with clearly sharper image, a sound system with better sound and so on. As for the product, "defence", it is the relative effect compared to a potential adversary that is interesting. If a nation though better capability of its defence risks losing a battle that it previously would have won as a result of that the opponent have improved capability even more, then indeed the defence product has declined in relative capability. This is the consequence even though the absolute capability has become higher.

This raises the question of what can be considered a "constant product" when it comes to defence.

Normally, a "constant product" is defined as a product with similar quality and features. In defence, it can be argued that a "constant product" is a product with an unchanged relative efficacy against a potential opponent, even though the product in absolute terms has higher performance.

This, in turn, raises the question of what the defence should be compensated for in decisions regarding the defence budget. Should it compensate for defence specific cost escalation of an unchanged relative capability against potential opponents or only for an unchanged absolute capability?

5.3 DEFENCE EQUIPMENT

5.3.1 Introduction

The most studied area of DSI/DSCE is defence equipment. The studies mainly focus on intergenerational inflation/cost escalation. Every new generation of a weapon system tends to generate both significant performance improvements per unit but with that high leaps in costs per unit. In the following sections we will present some recent results of different studies. The difference between DSI and DSCE is further elaborated with defence equipment as an example. Followed by an international comparison of how different countries has coped with the fast-rising unit costs of defence equipment – through reduced quantity or extended lifespans of equipment.

5.3.2 Studies of DSI/DSCE

The starting point is a Swedish study from The Swedish Defence Research Agency, FOI [8]. The results of the study are briefly summarized in the table below with the Swedish results compared to a number of international studies. Some international studies have calculated the cost trends as costs per unit but one study [4] has calculated weight-adjusted unit costs. FOI's results are thus shown as cost trends per unit and as weight-adjusted trends as well.

Cost trends for each system are compared with the general price trend as measured by the Consumer Price Index and are expressed as the difference in average annual growth compared with CPI. This means that +5.0% shows that the unit cost increased by 5.0% more than the increase in the CPI, not that the increase was 5.0%.

The period of observations for the cost trends are also shown in Table 5-1. The different studies are presented in the columns with our results from 2011 followed by results from the Norwegian Defence research Establishment, FFI [9], from Pugh [4] and some results from the US [10].

A difference between the studies are that FOI's study is based solely on Swedish observations but the other studies on international observations.

The results indicate a significant cost over time where the costs increases occur mainly in connection with generational change within the system type. The cost trend for the Swedish observations indicates a defence specific cost escalation that exceeds the CPI by 1-7% per year. A single equipment type with strong similarities to civilian production, field uniforms, have a lower cost trend than the CPI.

The international benchmark studies have arrived at similar results. The figures are often rather close to one another.

There is a tendency that the Swedish figures in many cases are slightly higher than indicated by the international results. An untested explanation to this could be it is the price you pay as a small, neutral country for developing and producing your own defence material, which is the case with fighter jets, submarines, corvettes and IFVs. The cost trend for fighter jets did slow down significantly with the latest generation shift from Viggen to JAS-Gripen.

Table 5-1: Cost Trends of Weapon Systems.

Weapon System	FOI (unit) Annual – Period	FFI Norway (unit) Annual – Period	Pugh UK (weight) Annual – Period	Other (unit) Annual – Period
Fighter Jet	+7,1 % -- 1953-2001 (+6,4 % weight)	+6,7 % -- 1940-2010 (+5,8 % weight)	4 % -- 1955-2005	+5,7%--1975-2005 US +6-7%--1944-2010 AU
Helicopter, light	+3,8 % -- 1963-2006 (+4,1 % weight)	+4,7 % -- 1950-2010 (+3,2 % weight)	4 % -- 1958-2006 (cargo, training, rescue)	
Helicopter, medium	+6,9 % -- 1969-2006 (+5,9 % weight)		6 % -- 1958-2006 (anti-submarine)	
Corvettes	+7,0 % -- 1963-2006 (+4,2 % weight)	+7,8 % / 1,4 % -- 1960-2000	1 % -- 1958-2004	
Submarines	+4,4 % -- 1960-1995 (+2,5 % weight)	+3,8 % -- 1907-1991 +9,4 % -- 1965-1991	3 % -- 1950-2010	+6 %--1960-2015 FFI +3,3%--1945-2010 AU
Battle Tanks	+0,7 % -- 1953-1996 (+0,3 % weight)	+2,2 % -- 1960-2006 (+1,2 % weight)	1 % -- 1950-2002	
Infantary Fighting Vehicles	+7,6 % -- 1965-2007 (+5,1 % weight)	+6,0 % -- 1960-2006 (+4,6 % weight)	4 % -- 1960-2010	+4,6%--1930-2010 AU
Armoured Personell Carrier	+4,5 % -- 1943-2010 (+3,1 % weight)		2 % -- 1960-2010	+3,3%--1960-2010 AU
Automatic Rifles	+2,8 % -- 1950-2010	+1,3 % -- 1868-2008	2 % -- 1935-2008	
Ammunition	+1,2 % -- 1983-2010			
Uniforms	-1,0 % -- 1990-2010			

From the FOI study we could see indications that the cost drivers of weapon systems over time had shifted from offensive characteristics and capabilities such as fire power, range of weapons to more defensive characteristics such as protection and transport.

What is the reason behind the rapid cost escalation of weapon systems?

An obvious reason is that superior weapon systems tend to win wars [10]. A key cost driver is the threat and the need for weapon systems to keep up a reasonable relative capability compared with potential future opponents in a conflict or a war. This arms race and the pursuit of maintaining or increasing relative power in comparison with an opponent are driving costs. This rush to dispose of defence equipment with higher performance than that of a potential adversary has led to defence material being referred to as *tournament goods* [11].

One can see many similarities (in Figure 5-5) in the unit costs of defence material with other competitive products such as transfer fees for elite soccer player which from 1957 pointed to an annual trend of about 8% over CPI.

Another example is Formula 1 cars where costs soared. It went so far that the Formula 1 teams began "disarmament negotiations" to set thresholds for performance to mitigate cost pressures.

Other reasons for a rapid cost escalation, beside the tournament-good aspect, of defence equipment can be found in:

- Reduced quantity, which results in lower economies of scale.
- Increasing fixed costs, which also tend to be shared by fewer units. Fixed costs, such as research, development, design and testing tend to account for a larger share of the cost when the number of

units produced decreases. The increased dependence on advanced software and the increasing need for integration with other weapons systems also contributes to increasing fixed costs.

- A different and less competitive market situation with few buyers and sellers (oligopoly) and/or bilateral monopoly (one buyer/one seller) leads to another price formation than in markets more exposed to competition. This is in some cases valid for Sweden, with its traditionally large defence industry with the Swedish Armed Forces as the dominant customer.
- The international division of labour is less evident in production of defence equipment. The localization of production to low-cost countries, which often takes place in civilian production, is not as evident in military production. Civil production is often localized to the countries that can offer the lowest production costs, often low-wage countries. The firms are continuously looking for the cheapest production. This is seldom the case in military production. Military production has thus not been able to take advantage of efficiencies of international division of labour. One of the reasons for this is that military efficiencies of international division of labour. One of the reasons for this is that military production is often high tech and specialized and that the high level of technical expertise required is not available in low-wage countries.

But in some cases, comparative advantages can be obtained, and when it does it can mean a slower cost escalation. An indication of that can be observed in the table of cost trends above – for uniforms. The production of uniforms has made almost the same journey as the civilian textile industry in search for cost-effective localization of production.

Both our and international results [4] indicate that the equipment that exists in the civilian market and is used in defence or defence equipment that otherwise are very similar to commercial systems have a lower cost trend. This is probably an effect of economies of scale, market situation and international division of labour.

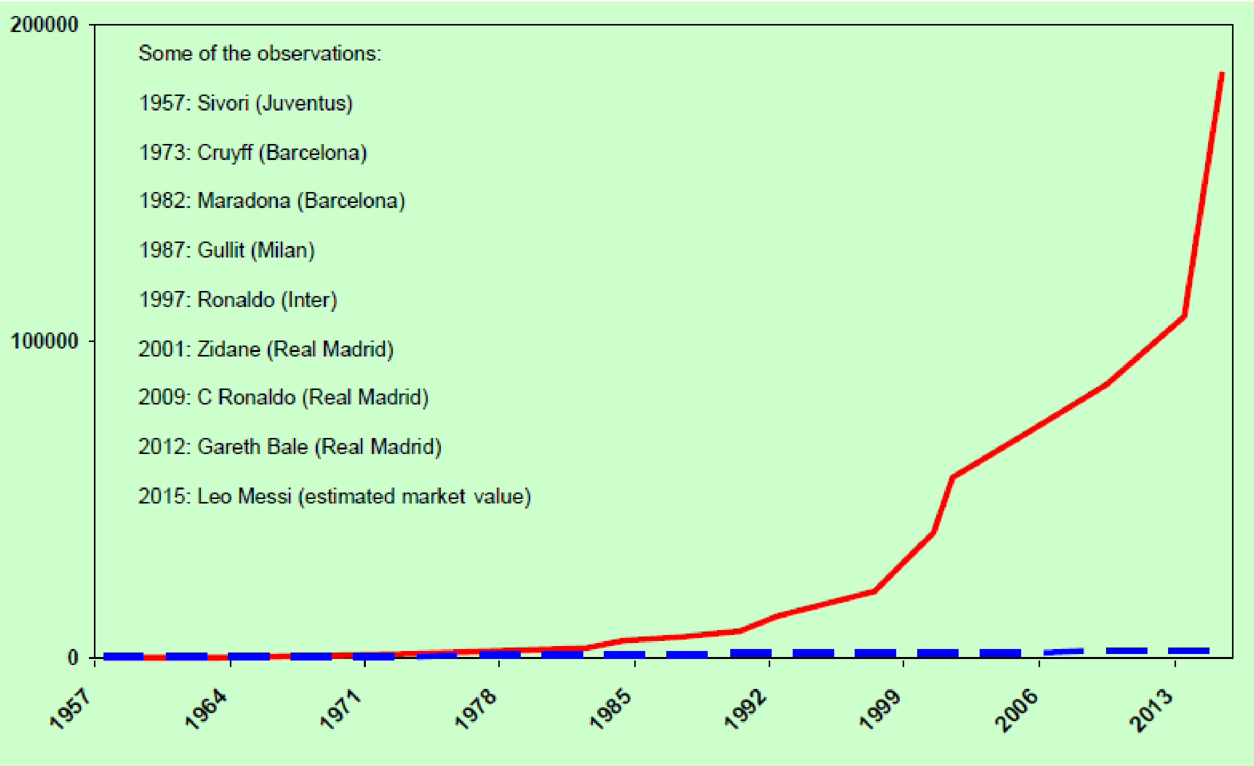

Figure 5-5: Price Index of Top Soccer Players (Continuous Curve) – Compared to CPI (Cross-Hatched Curve).

- Protectionism, where a nation favours the domestic defence industry, which leads to the normal gains of free trade not occurring in the production of defence equipment. Protectionism can also be a consequence of a wish not to transfer technology to potential opponents and/or international, competing defence industry.

  Other reasons that limit international free trade and assimilation of international comparative advantages in the spirit of David Ricardo (1817) [12] are legal and security matters along with property protection.

- The possibilities of substitution are lower in military production than civilian. This reduces the options to substitute products with a rapid cost escalation and thus higher relative prices with products with a slower cost escalation.

5.3.3 Defence Equipment – Inflation and Cost Escalation

Section 5.1 touched upon the concepts of defence specific inflation and defence specific cost escalation. In the discussion below and the figure below, I relate these concepts closely to defence equipment. But, in principle, the same reasoning could be applicable to other defence resources, but equipment is probably the area where the differences between inflation and cost escalation are greatest.

Price and cost of defence equipment is partly due to economy-driven factors which consists of the price increases of the resources needed for the production of armaments. This makes the defence equipment more expensive even for an identical product without improved performance (illustrated by the light green part of the bar in Figure 5-6). This is the "pure" price change for defence equipment, the *defence specific inflation*.

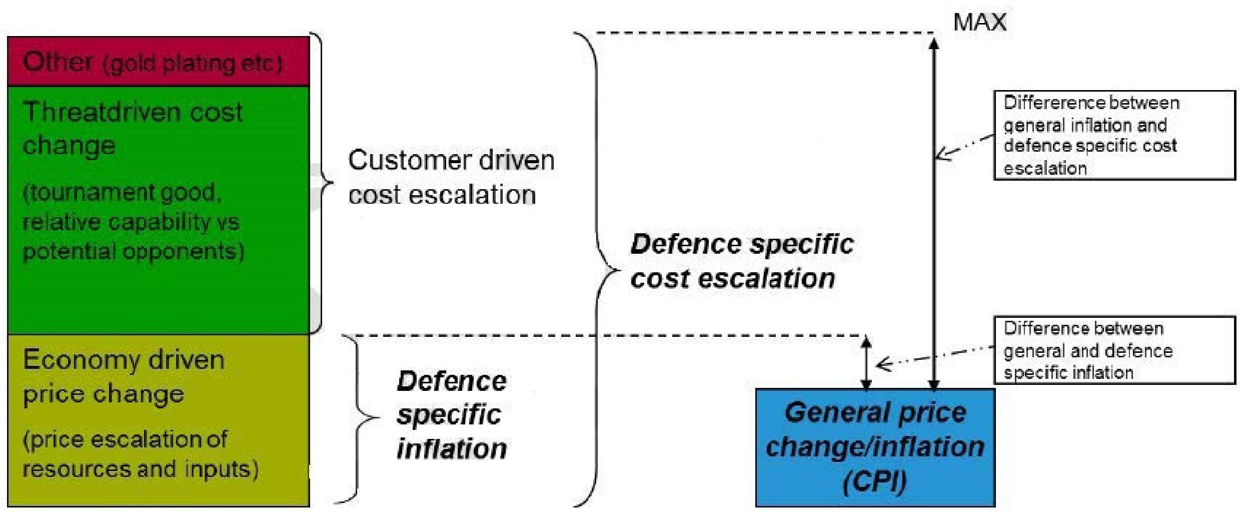

Figure 5-6: Defence Specific Inflation and Cost Escalation.

In addition to these price changes, there will be threat driven changes in unit cost related to demands for higher performance, better quality and expanded functionality of weapon systems (the dark green part of the bar in the diagram). Other demands may also contribute to further cost escalation, vainer irrational demands such as "*gold plating"* or "*nice to have"* (the purple part of the bar). These demands along with the threat driven together form the cost escalation that can be seen as the *customer driven cost escalation*. This cost escalation mainly occurs with generational shifts when older equipment is replaced with new, improved, equipment.

The *economy-driven* increases in unit price and the increase in unit costs due to higher customer requirements, *customer driven cost escalation* together comprise the *defence specific cost escalation*.
If we compare the defence specific inflation with general inflation (in Figure 5-6, illustrated by the blue bar, to the right) we find a difference (as shown by the shorter vertical arrow).[1] The difference between the defence specific inflation and general inflation can be seen as the "pure" difference in price trend over time for unchanged products.

If we, however, compare the defence specific unit cost escalation with general inflation, the difference is even greater (shown in Figure 5-6 by the longer vertical arrow).

Statistics from the USA [13] indicate that cost escalation is primarily caused by customer driven factors in terms of performance, enhanced features and higher quality and less by economy-driven factors such as inflation and higher prices of production resources.

Studies from RAND [14] regarding costs of fighter jets indicate that the main reasons for cost escalation are the customer driven factors (requirements for functionality, performance and complexity, etc.) and, to a smaller extent, are dependent on economy-driven factors (inflation and price trend of production resources). An overall increase in the unit cost of the aircraft model F-15 from 1975 to unit cost of aircraft model F-22A in 2005 was observed to be an average of 10% per year. The increase in unit costs was approximately 2/3 dependent on customer driven causes and only about a 1/3 of economy-driven causes. The US Defence Price Index [13], which is based on the military's own price trends and not on general-called proxy indices suggest that the pure price development for "equivalent products" of defence equipment have sometimes been lower than general inflation.

However, we can discuss what should be considered as an "equivalent" product over time when it concerns defence equipment. This includes a product with the same capacity in absolute terms (the same fire power, the same range, same speed, etc.) or an "equivalent" product with the same relative performance compared to an opponent? In the latter case, the part of the unit cost increase that occurs due to threat driven demands and a need for improved performance to meet a potential opponent, can be considered as price changes and consequently defence specific inflation.

The reasoning above leads to a number of questions: What price and cost change should be compensated? And, how should the price and cost changes be compensated? In this case, the Swedish system for price compensation for the Armed Forces, FPI, is used to illustrate the discussion. Should they be compensated through appropriation adjustments and/or through "automatic" price and wage compensation, such as the Swedish Defence Price Index (FPI)? What should be taken into account in the explicit budget decisions, and what should be taken into account in the price and wage compensation as calculated by FPI?

The proxy indices used in FPI to compensate for price changes of defence equipment compose of two different indices – one for the domestically produced and one for the imported defence equipment. The domestic part (28% of total budget for the Swedish Armed Forces) is compensated by the Producer Price Index for the private sector and the imported part (10% of total budget) by the Import Price Index for Engineering Goods.

The choice of proxy indices for the domestic part was changed in 2012. The earlier index was a composite index where the resource mix of the defence industry located in Sweden was taken into account. The defence industry differs a lot from the private sector as a whole partly due to being more personnel intensive. This is in turn a consequence of the high level of research and development within the defence industry. The R&D share of the total turnover is 18% compared to just over 1% for the industry in general.

[1] Difference need not, as in the example being positive = higher defence – specific inflation than general but the opposite may occur.

Since the change in 2012, the proxy index for defence equipment has dropped causing negative compensation for cost escalation of defence equipment. And the losses of compensation from the changes in the construction of the index were higher than the raises in appropriations that simultaneously were explicitly decided by the Parliament. The one hand gave and the other hand, "the invisible hand", took – thus erasing the intentions by the Government and the Parliament.

As in FPI, compensation with general proxy indices is an option. It is simple and it cannot be influenced by the organization that is to be compensated. This will probably result in a lack of compliance with the Armed Forces actual price and cost escalation and would lead to under- or over-compensation dependent on choice of proxy indices. This may require adjustments in the defence budget decisions when this difference between the proxy indices and actual price and cost escalation over the years amounts to large sums. If not, then any over- or under-compensation would affect the business. The effect is that this would likely result in "less defence" than was intended in the budget decisions.

Another possibility is to design price and wage compensation indices as close to actual price and cost changes as possible reflecting the Armed Forces' "pure" price trends over time for unchanged product. This does not create the same need to frequently adjust over- or under-compensation in the decisions on the budget. The politicians can then concentrate on considering and deciding on the "real" changes in the defence budget from demands on the equipment as a consequence of the world situation and the threats. The decisions on "real changes" emerge particularly with generational shifts of defence equipment.

Should increases in the performance of defence material be subject to specific, explicit budget decisions or should it, in whole or in part, be built-in and covered by the price compensation of FPI?

Since there is a reduced compensation for increases in labour costs, due to the requirement for productivity that is built-in the FPI, you could argue that FPI should compensate for the threat-driven cost escalation of defence equipment. According to Solow's growth model [15], the growth in production (Δ P) is determined by the quantity of inputs of labour (Δ L) and capital, equipment, machines etc, (Δ C) and the innovation and improvements in technology ("technology factor", Δ T). The technology factor is the growth that cannot be explained by increased inputs in terms of labour and capital. The production function states that: $\Delta P = \Delta L \times \Delta C \times \Delta T$.

This could be applied on FPI, suggesting that if productivity improvements are demanded from the Swedish Armed Forces, as it is in FPI, you consequently will also have to allow for compensation for the costs of better technology and improved defence equipment.

FPI did allow for "technology"-driven cost escalation until year 2000. On top of the proxy index, there was an extra 1.5% per year added to the compensation for price changes on defence equipment. But that "extra compensation" disappeared in 2000.

One possibility would be to regard the need for price and wage compensation to be equal to the entire defence specific unit costs up to the "MAX" level in the diagram above. This would probably, however, involve an over-compensation. It would allow for an increase in the quality without reducing the quantity of materiel systems.

Such a high compensation could under certain circumstances with a worsening world situation and growing threats be reasonable. But almost all countries have in modern times, except in moments of arms race, met the increase in unit costs due to higher performance and quality by a *decrease in quantity*. A reduced quantity with successively fewer objects from one system generation to another has been a way of funding the increased performance, higher quality and expanded functionality of newer systems (Augustine, 1983, Hartley, 1991). A full compensation for cost escalation, MAX-level, would, under such conditions, improve the relative capability and can be seen as over-compensation.

Better systems are of course also a force multiplier that allows you to reduce the number of units without reducing quality. So, there is a question of how to balance quality and quantity to get the most “bang for the bucks”. This balance is influenced by the characteristics and the magnitude of the threat.

The major cost increases occur in occasional leaps in connection with generational changes but a study by the National Audit Office [16] indicates a more rapid cost than CPI even within a single generation of a system. This is due to the contracts with the defence industry often having clauses on indexation of wage and price increases that often leads to higher cost escalation than CPI.

Another way to finance the higher unit costs have been using and maintaining the equipment longer, thereby *extending the life* of the equipment. An earlier generation of a material system that cost $20 million per unit was succeeded by a new generation costing $36 million per unit. The price per unit has thus increased by 80%. If the first generation had a 20-year lifespan, the annual cost (depreciation) was $1 million. If next generation had a longer lifetime of 30 years, the annual cost (depreciation) is $1.2 million. The cost increase would with this approach have been limited to 20%. Longer lifecycle of equipment could in this way be used to finance the costs of higher quality.

We have studied how Sweden and some other countries have financed the increase in unit costs of defence equipment, by *decreases in quantity* and/or *extended lifespans*. The comparison suggests that other countries, just like Sweden, have financed rising unit costs and better capability of defence equipment with reduced quantity. However, Sweden has been one of the countries that more than others have paid for quality with quantity. Reduced numbers have been a more important means of financing the increased unit costs of weapon systems in Sweden compared with other countries. The only countries that are level with Sweden in reduced quantity are Germany and Russia/Soviet Union since the end of the Cold War. In Russia, however, this trend has been reversed over recent years.

5.3.4 Reduced Quantity – International Comparison

Table 5-2 and Table 5-3 show how quantity has developed in some countries from 1975 (during the Cold War) and 1990 (the final phase of the Cold War) until 2013. The data is collected from various sources with Military Balance [17] as the main source. Military Balance is an internationally recognized and standardized source. In some cases, we have used other sources to ensure that comparisons are as valid as possible.

Table 5-2 expresses the quantity of some of the most important weapon systems in 2013 compared to 1975 as a “quantity index” where 1975 = 100. The lower the “index”, the stronger the number of reductions in quantity. Some data from 1975 are missing shown by (-), whereas data from 1990 are more complete. Finland has never had any submarines (expressed by NA).

Generally, Sweden shows low indices. Germany and Russia/Soviet Union also exhibit generally low and, in many cases, lower figures. Our Nordic neighbours exhibit, with some exceptions, higher indices as well as France and Poland.

Table 5-3 shows the same information, but the base year for the index is 1990, i.e., 1990 = 100. Denmark has in recent years completely dismantled its submarine force, hence the index value = 0.

5.3.5 Average Age of Defence Equipment

An international comparison has been made between with the average age of defence material. The results are reported in Figure 5-7.

In many other countries, there is a clear trend towards increased service life of the equipment. This trend is not as clear in Sweden. This suggests that other countries have been more inclined than Sweden to make use of increased lifespans to finance the cost increases of better capability of defence equipment.

Table 5-2: Quantity of Weapon Systems 2013 Compared to 1975.

	Sweden	Denmark	Finland	Norway	Poland	France	Germany	Russia[2]
Fighter Jets	24	39	96	50	13	84	64	27
Helicopters	54	118	200	86	102	89	54	42
Battleships	19	68	125	21	16	54	51	16
Submarines	29	0	NA	40	83	43	18	28
Anti-aircraft	4	-	50	13	-	-	1	25
Tanks	14	23	89	28	27	12	8	42
Armoured vehicles[3]	150	112	859	-	-	-	36	100
Artillery	5	7	-	5	-	-	13	-

Table 5-3: Quantity of Weapon Systems 2013, Compared to 1990.

	Sweden	Denmark	Finland	Norway	Poland	France	Germany	Russia[2]
Fighter Jets	24	39	96	50	13	84	64	27
Helicopters	54	118	200	86	102	89	54	42
Battleships	19	68	125	21	16	54	51	16
Submarines	29	0	NA	40	83	43	18	28
Anti-aircraft	4	-	50	13	-	-	1	25
Tanks	14	23	89	28	27	12	8	42
Armoured vehicles[3]	150	112	859	-	-	-	36	100
Artillery	5	7	-	5	-	-	13	-

Many of these countries have a larger “material differentiation” when it comes to age and generations of weapon systems, with a mix of older and younger items and generations. This leads to longer depreciation periods for each generation of systems. Various military units have different levels of modernity and quality of equipment depending on the task. There is a “high-low mix” of modern and highly capable and older, less capable equipment.

The Swedish operational organization with its limited number of units, however, makes such a material differentiation difficult. Most types of military units that exist today are in the singular.

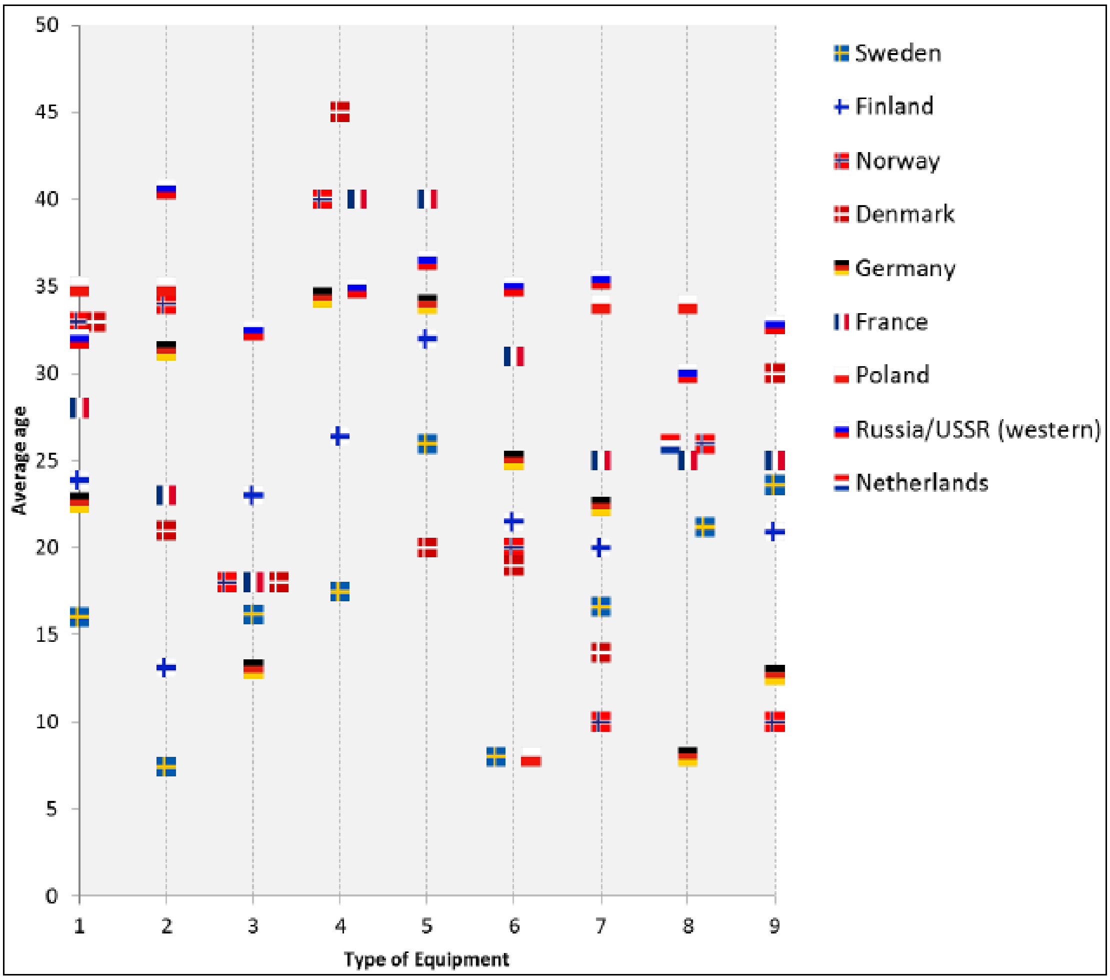

Figure 5-7: Average Age of Different Material Systems in 2013.

The systems types are shown by the x-axis where:

1 = Fighter Jets;

2 = Helicopters;

3 = Tanks;

4 = Infantry Fighting Vehicles;

5 = Armoured Personnel Carriers;

6 = Armoured Cars;

7 = Battleships;

8 = Submarines; and

9 = Anti-Aircraft.

Sweden normally has quite modern systems, with the exception of anti-aircraft, compared to other countries. The diagram shows a static picture of the average age of different weapon systems in year 2013. A more dynamic study from 1975 and 1990 would show that the average age of weapon systems in Sweden has been rather constant while most other countries show a tendency to increase the lifespans of defence equipment.

5.3.6 Personnel and Productivity

The Swedish example illustrates defence specific cost conditions when it comes to personnel and productivity. The increases in wage costs for defence employees seems to be under normal, steady-state conditions, to comply fairly well with the general increases in wages.

But there is a productivity requirement for the Armed Forces. According to this requirement, the Swedish Armed Forces are supposed to have the same productivity as the private service sector.

Productivity requirements mean that the Armed Forces must maintain an unchanged performance with successively reduced staffing or reduce costs by other ways of achieving the equivalent productivity. Savings achieved through lower ambitions are *not* productivity.

According to “Baumol’s cost disease” [18] the public sector for various reasons cannot provide the same productivity as the private sector but will nonetheless have to follow the wage escalation of the private sector. And, as we indicated this seems to be the case for the Swedish Armed Forces in a steady-state situation.

The problem of measuring output in defence makes it hard to calculate or prove the level of productivity in defence. So, discussions about productivity in defence have to build on circumstantial evidence and logical, rather than calculated, deduction. A lot of thinking has been done about output measures and productivity in defence, but the conclusion is that there are no outright, simple solutions (e.g., Ref. [19]).

FOI has argued that there are special circumstances in the Armed Forces that complicate increased productivity. One is the drawdown phase underway since at least the mid-90s with a substantial decrease in defence volumes that has made it harder to achieve economies of scale.

The fact is that the “benchmark for productivity” in the private service sector as well as in the private sector as a whole often shows drops in productivity during periods of fall in demand for their products and services. Even the profit-driven private sector has problems with productivity when volumes decrease. And a lower utilization of capacity during these periods is often an explanation. This fact supports our hypothesis of slow and perhaps even negative productivity growth in defence in the past 15-20-year period. High fixed costs in defence, along with a lower utilization of capacity, when volumes drop makes it hard to comply with the productivity requirements facing the Armed Forces.

It is plausible that productivity and efficiency requirements for the Swedish Armed Forces under steady-state conditions are reasonable to create incentives to streamline operations but more limited than the productivity requirements for the Armed Forces suggests.

The following other factors, in addition to reduced economies of scale through reduced defence volumes, also suggests that the potential for increased productivity is relatively low in the defence sector compared to the private service sector:

- A majority of the staff in the Swedish Armed Forces has dual roles, including being a part of the product – the operational organization with its units, as well as being part of the production, such as training new recruits, acquisition of defence equipment and administration. The dual roles mean that an opportunity for improving the efficiency of production can be blocked by a persistent need for the same competence in the operational units – brigades, battalions, companies, etc.
- The cost of developing new material systems are large and with each generation production runs gets shorter meaning that the unit costs rise.
- The market is often characterized by bilateral monopoly (one seller and one buyer) or oligopoly (few sellers and one buyer).

- Political constraints and decisions limit the freedom of action of the Armed Forces to a greater extent than the private service sector and other government agencies, to implement certain savings measures. Productivity gains can largely be achieved through organizational changes, base closings, introduction of effective solutions for the supply of personnel and effective weapon systems. To some extent political constraints, employment, regional policy, industry policy, etc., reduce the options for the Armed Forces to improve productivity. Other decisions on defence, for example, acquisition decisions regarding defence material, has been influenced by other considerations than solely by defence efficiency, such as industrial policy and international cooperation.
- Limited substitution possibilities. Another factor that is linked to productivity and the ability to limit the effects of price trends are the Armed Forces substitution possibilities. If the Armed Forces could change its consumption pattern to adapt to changing relative prices the effects of price escalation could be mitigated. But the potential to replace goods/services that have had significant price increases with those that have had a lower price trend is lower than in most other sectors. Substitution possibilities of defence are usually considerably more limited than for private consumers, and for other government activities. Goods are often unique, and substitutes are often lacking.
- One factor that probably also had an inhibitory effect on the productivity was the end of the Cold War and the fall of the Berlin Wall caused an “identity crisis” and political ambivalence. For a rather long period the Swedish defence had no clear “business idea” and lacked a strategic direction. The absence of a clear direction has meant that the most important “guiding principle” for the design of efficient defence was lacking and has affected productivity negatively.
- The Swedish Armed Forces have been under constant change since the ‘90s. An activity in a stage of restructuring and reduction will find it harder to increase productivity compared to expanding activities.

As a matter of fact, the National Accounts and GDP calculations are built on the assumption that there is no productivity in the defence and in many other public sectors. The value of the products is assumed to the costs of the inputs in terms of resources to produce the output. This shall not be interpreted as evidence for non-existent or low productivity. It has to do with the difficulties to measure and value the output that we discussed earlier in this chapter.

5.4 REFERENCES

[1] Nordlund, P., 2015, Defence Specific Inflation – A Swedish Perspective. Defence and Peace Economics 27(2), pp. 1-22.

[2] Kirkpatrick, D., and Pugh, P., 1983, Towards the Starship Enterprise – Are the Current Trends in Defence Unit Costs Inexorable? London: Aerospace.

[3] Kirkpatrick, D., 1995, The Rising Unit Cost of Defence Equipment – The Reasons and Results, Defence and Peace Economics 6(4), pp. 263-288.

[4] Pugh, P., 2007, Retrospect and Prospect: Trends in Cost and Their Implications for UK Aerospace, Defence and Peace Economics 18(1), pp. 25-37.

[5] Solomon, B. 2003, Defence Specific Inflation: A Canadian Perspective, Defence and Peace Economics, 14(1), pp. 19-36.

[6] Augustine, N.R., 1983, Augustine’s Laws and Major System Development Programs. Revised and enlarged. 2nd ed. New York: American Institute of Aeronautics and Astronautics. ISBN: 0915928817

[7] Hartley, K., 2012, White Elephants. The Political Economy of Multi-National Defence Projects. ISBN: 978-2-87555-010-1. Brussels : New Direction – The Foundation for European Reform.

[8] Nordlund, P., Åkerström, J., Öström, B. and Löfstedt, H., 2011, Kostnadsutveckling för försvarsmateriel. Report FOI-R–3213–SE.

[9] Kvalvik, S., Johansen, P.K., 2008. Enhetskostnadsvekst på forsvarsinvesteringer (EKV-I). FFI-rapport 2008/01129.

[10] Kirkpatrick, D.L., 2004, Trends in the Costs of Weapon Systems and the Consequences. Defence and Peace Economics 15(3), pp. 259-273. ISSN: 1024-2694.

[11] Kirkpatrick, 2003. A UK Perspective on Defence Equipment Acquisition. Singapore: Institute of Defence and Strategic Studies.

[12] Ricardo, D., 1817, On the Principles of Political Economy and Taxation, London: John Murray.

[13] US Bureau of Economic Analysis, https://www.bea.gov/ (Accessed 2017).

[14] Arena, M.V., Younossi, O., Brancato, K., Blickstein, I., Grammich, C.A., 2008, Why Has the Cost of Aircraft Risen? A Macroscopic Examination of the Trends in US Aircraft Costs Over the Past Several Decades. Santa Monica CA: RAND Corporation.

[15] Solow, R.M., 1956, A Contribution to the Theory of Economic Growth, The Quarterly Journal of Economics, 70, Feb, 1956.

[16] NAO, 2004, Ministry of Defence: Major Projects Report 2004. https://www.nao.org.uk/report/ministry-of-defence-major-projects-report-2004/ (Accessed May, 2019).

[17] International Institute for Strategic Studies. https://www.iiss.org/press/2020/military-balance-2020 (Accessed May, 2019).

[18] Baumol, W. J., Bowen, W.G., 1966, Performing Arts: The Economic Dilemma, New York: The Twentieth Century Fund.

[19] Hartley, K., 2011. The Economics of Defence Policy. London: Routledge.

Chapter 6 – CAPABILITY COSTING

6.1 INTRODUCTION

Calculating a capability's cost is not a straightforward procedure. Since the majority of capabilities are provided by multiple force structures, the annual cost to provide a capability is not simply the sum of the relevant force structure's Equivalent Annual Cost (EAC) [1], [2], [3] As an example, the primary Search and Rescue (SAR) capability provided by the Canadian Armed Forces is the provision of aeronautical SAR (search for downed aircraft) and the coordination of aeronautical and maritime SAR systems [4]. A combination of resources provides this capability, including operational commands, naval and air force structures, and volunteer organizations. The naval and air force structures' EAC costs should not be fully attributed to the SAR capability, since some of these force structures provide other capabilities (e.g., the CH-124 Sea King helicopters and CP-140 Aurora aircraft provide aeronautical SAR, but their primary function is to provide intelligence, surveillance, and reconnaissance). A more accurate estimate is to attribute the portion of the force structures' EAC to the various capabilities they provide based on the hours of readiness training conducted for the capabilities. The benefit of using readiness training to attribute force structures' EAC to capabilities is that the cost of a capability is then not dependent upon *the decision to employ a capability*, rather *the investment decision to have the option to employ a capability*.

This chapter describes how Time-Driven Activity-Based Costing (TDABC) [5] may be used to calculate the cost of capabilities through attributing force structures' EAC to capabilities based on readiness training. TDABC, which is a streamlined version of Activity-Based Costing[1] in terms of data collection and processing, is a practical approach to calculate these costs. In addition, its output provides decision-makers insight into force structure utilization, identifies processes that may be inefficient, and may support further studies regarding the variety and mix of force structures and capabilities.

The remainder of this chapter is organized as follows. First, an explanation of how a force structure's EAC may be attributed to capabilities using readiness training, is presented. Next, we present a set of examples that show how a capability's cost is calculated using this approach, discuss several implementation issues, and an example of how it may be integrated within the capability-based planning. The last section presents a summary.

The chapter is partly built on a scientific report written by a member of NATO SAS-092 [6].

6.2 ALLOCATING FORCE STRUCTURE COSTS TO CAPABILITIES

TDABC has been applied within a variety of domains, including electronics [7]; healthcare [8], [9]; library sciences [10]; and tourism [11]. However, since the defence organizations do not perform activities, or create products, in a business sense, the components of TDABC must be interpreted within a defence context. Table 6-1 lists the high-level TDABC components and their interpretation within the capability costing problem.

Table 6-1: TDABC Components and Their Interpretation Within Capability Costing.

TDABC Component Interpretation		
Standard	**Capability Costing**	**Explanation.**
Organization	Force structure	An organization is a set of resources that is used to perform activities or create products. The concept of an organization

[1] For comparison of activity-based costing and time-driven activity-based costing, see Ref. [12].

TDABC Component		Interpretation
		is replaced by a force structure (e.g., fleet of aircraft, ships, vehicles), since force structures are the entities that produce capabilities. In this interpretation, a force structure includes all components (i.e., personnel, infrastructure, equipment, etc.), both direct and indirect, required to produce its associated capabilities.
Activity	Capability	An organization's activities/products are replaced with capabilities, since capabilities are the products of force structures.
Activity cost	Capability cost	An activity's annual cost is replaced with a capability's annual cost.

Figure 6-1 shows an example of the relationship between the force structure (organization) and capability (activity/product) components. The example shows two force structures, labelled 1 and 2, and three capabilities, labelled 1 through to 3. Force structure 1 provides Capability 1 and 2 and Force structure 2 provides Capability 2 and 3. The force structures' EAC are attributed to the capabilities as follows:

- x% and (100-x)% of Force structure 1's EAC is attributed to Capability 1 and 2, respectively; and
- y% and (100-y)% of Force structure 2's EAC is attributed to Capability 2 and 3, respectively.

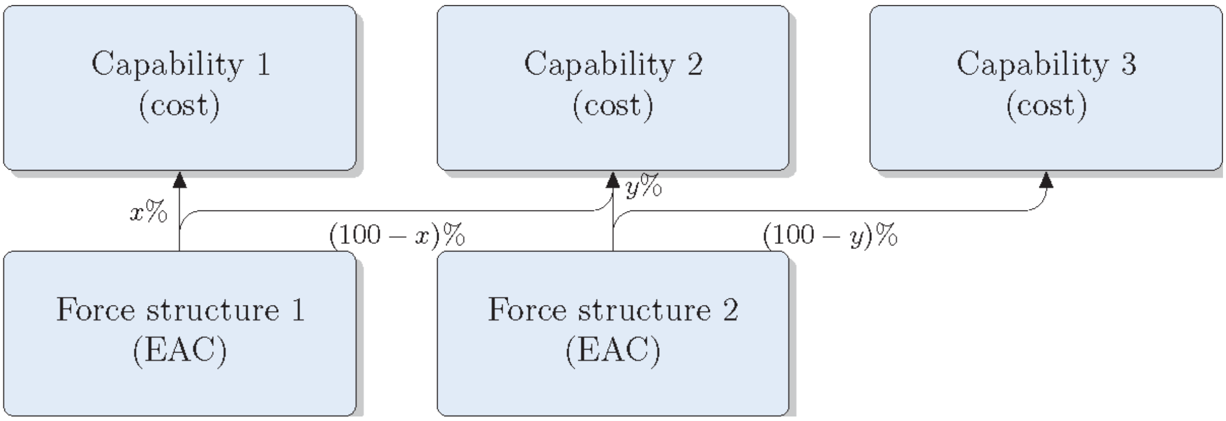

Figure 6-1: Relationship Between TDABC Components Within Capability Costing.

A capability's cost is then the sum of the attributed force structures' EAC. For example, the cost of Capability 2 is:

$$\text{Capability 2 cost} = \frac{100-x}{100} \cdot f_1 + \frac{y}{100} \cdot f_2$$

where f_1 is the EAC of Force structure 1 and f_2 is the EAC of Force structure 2.

The question is then, *how to determine the allocation of a force structure's EAC to the capabilities it provides*? TDABC attributes resource costs (i.e., an organization's capacity cost rate, such as dollars per hour) to activities/products based on the activities'/products' demand[2] for resources (i.e., capacity usage, such as hours). In TDABC, these are defined as follows:

- A resource's capacity cost rate is the resource's cost of capacity (i.e., total cost of supplying the resource's capacity) divided by the practical capacity of the resource (i.e., hours available to provide the resource).
- An activity's/product's capacity usage is the demand (typically time) for resource capacity.

Force structure usage by capabilities may be interpreted in two ways: 1) Usage in operations; and 2) Usage in training. While both interpretations are valid, the latter is preferred since force structures must train to be able to produce capabilities, but capabilities may or may not be employed during operations. For example, suppose a force structure of fighter aircraft trains to produce an air-to-air capability so that it may be used when required; however, this capability may never be employed within an operation. Thus, using training to attribute force structures' EAC to capabilities ensures that the cost of a capability is not dependent upon the *decision to employ a capability*, rather *the investment decision to have the option to employ a capability*.

In general terms, there are three types of training: initial cadre training (i.e., baseline training, common training), readiness training (i.e., ongoing training to maintain a capability), and operation-specific training (i.e., pre-employment training for a specific operation). Since initial cadre training is non-capability specific and operation-specific training is dependent upon capability employment, readiness training is the type of training that is most appropriate to attribute a force structure's EAC to capabilities. Thus, a force structure's capacity cost rate and capabilities' capacity usage are defined as follows:

- **Force structure capacity cost rate:**
  - **Cost of capacity**: A force structure's cost of capacity is its EAC, including historical cost, betterments, operating costs, etc., less the EAC of readiness training that the force structure performs. The readiness training costs should be directly assigned to the appropriate capabilities being trained for. The cost of capacity is measured in monetary units.
  - **Practical capacity of resources**: Force structures are typically planned based on an annual usage (e.g., yearly flying rate for aircraft, sea-days for ships). For example, suppose a force structure's yearly planned practical capacity is represented by the sum of the areas of the rectangles in Figure 6-2, where the area of each individual rectangle represents a proportion of the total capacity and the rectangle's colour represents it purpose (i.e., red is training, yellow is operations, blue is other). The proportion of capacity used for readiness training is the practical capacity of interest. The practical capacity of resources is measured in hours.
  - **Capability capacity usage**: A capability's capacity usage of a force structure's readiness training capacity is the number of readiness training hours performed in a given year for the capability.

Given these definitions, and the required data, the yearly cost *to be able to provide a capability* can be calculated. The next section presents several examples of how these calculations are performed, taking into account several practical issues.

[2] Basing attribution rules on demand for resources is similar to the approach that is used in force structure costing models, such as the Strategic Cost Model [2], where three attribution rules are used – number of people required for training and personnel support; equipment operating costs for maintenance and overhaul; and personnel and operations and maintenance costs for demands, such as base support.

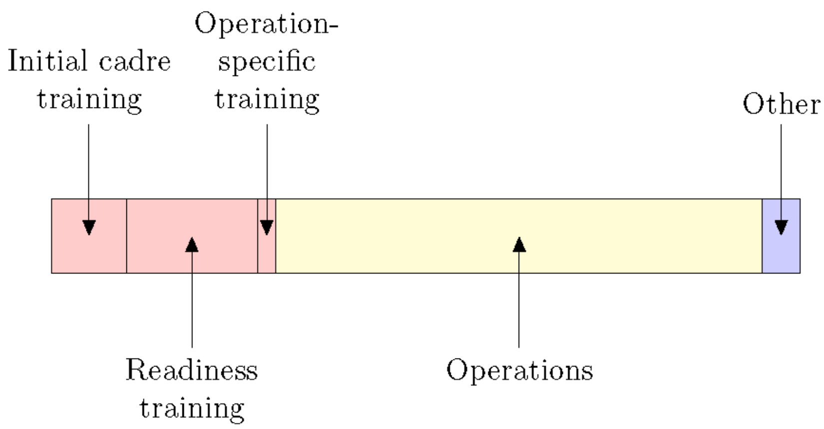

Figure 6-2: Example Breakdown of a Force Structure's Planned Practical Capacity.

6.3 EXAMPLES

In this section, we present five examples that demonstrate how TDABC is used to calculate a capability's cost. The examples range from basic, which do not require handling of any practical issues, to more complex, which take into account several practical issues. In addition, the examples presented use generic, rather than specific, force structures, so that the examples are applicable to the widest audience.

6.3.1 Basic Force Structure

Suppose a force structure f that has 15 units (e.g., helicopters), a per unit total planned capacity of 500 hours per year (total planned force structure capacity 7,500 hours per year), and a total planned readiness training capacity of 2,000 hours per year. Suppose the EAC of the fleet is \$150 million (i.e., lifecycle cost of \$4.5 billion over 30 years), excluding readiness training costs. The capacity cost rate is:

$$\text{Capacity cost rate} = \frac{\$150\text{ million}}{2{,}000\text{ hours}} = \$75{,}000\text{ per hour}$$

Suppose f produces two capabilities, labelled Capability 1 and 2, that have costs c_1 and c_2 respectively. The force structure f conducts 750 hours per year (h_1) of readiness training (r_1) for Capability 1 and conducts 1250 hours per year (h_2) of readiness training (r_2) for Capability 2. The annual cost of readiness training r_1 is \$0.5 million and r_2 is \$5 million. The capabilities' costs are computed as:

$$c_1 = \$0.5\text{ M} + h_1 \cdot \frac{\$75{,}000}{\text{per hour}}$$

$$c_2 = \$5\text{ M} + h_2 \cdot \frac{\$75{,}000}{\text{per hour}}$$

where the first term in each equation is the cost of readiness training for the capability. The capabilities' costs, c_1 and c_2, are shown in Figure 6-3. The total cost of both capabilities is \$155.5 million; \$150 million from the force structure's EAC (less readiness training costs) and \$5.5 million due to readiness training costs. Since Capability 2 has a higher demand for resources (i.e., training hours) than Capability 1, it has a proportionally higher cost.

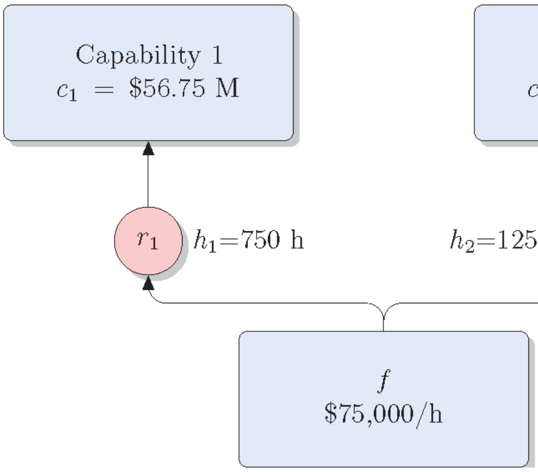

Figure 6-3: Example 1 – Basic Force Structure. The red circles indicate the readiness training associated with each capability.

The force structure f in the above example uses the total planned readiness training capacity per year (i.e., 2000 hours) to train for the capabilities it provides. However, situations may arise where the used training capacity is less than the planned capacity, such as: 1) Readiness training is ramping over a period of time (e.g., readiness training for Capability 1 is as follows: year one is 250 h, year two is 500 h, year three and four is 750 h); and 2) Extra readiness training capacity was planned as contingency (e.g., readiness training for Capability 1 is 500 h and for Capability 2 is 1000 h, resulting in a training contingency of 500 h). In these types of situations, the readiness training hours, h_1 and h_2, used to calculate the capabilities' costs should be the used readiness training hours. The cost of the unused readiness training capacity should be assigned to *unused readiness training capacity* rather than to the cost of the capabilities.

6.3.2 Multiple Readiness Levels

Readiness means different things to different people (e.g., state of preparedness of a force structure to perform operations, the ability to deploy quickly and perform initially in wartime, ability to be committed to combat), and thus there is no common or widely accepted definition [13]. In an effort to be relevant in the widest range of applications, we will not define the term *readiness*. Rather, we will assume that a force structure has defined readiness levels that can be distinguished from each other.

Given the force structure f described in the previous example, suppose there be two readiness levels for Capability 2: a low level $r_{2,1}$ (e.g., ability to deploy in a month) and a high level $r_{2,2}$ (e.g., ability to deploy in a week). As in the previous example, the force structure f conducts 750 h per year (h_1) of readiness training (r_1) for Capability 1. For Capability 2, it conducts 250 h per year ($h_{2,1}$) of readiness training for the low level ($r_{2,1}$) and 1000 h per year ($h_{2,2}$) of readiness training for the high level ($r_{2,2}$). The annual cost of readiness training r_1 is $0.5 million, for $r_{2,1}$ is $2 million, and for $r_{2,2}$ is $3 million. The capabilities' costs are computed as:

$$c_1 = \$0.5\text{ M} + h_1 \cdot \frac{\$75{,}000}{\text{per hour}}$$

$$c_2 = \sum_{i=1}^{2}\left(\beta_i + h_{2,i} \cdot \frac{\$75{,}000}{\text{per hour}}\right)$$

where the term b_i is the cost of readiness training for $r_{2,i}$. In TDABC, the above equations are known as *time equations*. The capabilities' costs are shown in Figure 6-4. In this example, the demand for resources varies within Capability 2. Although including greater detail about the levels of readiness has not altered the capabilities' costs, it does highlight that the resources required to train for the low readiness level are significantly lower than those required for the high readiness level.

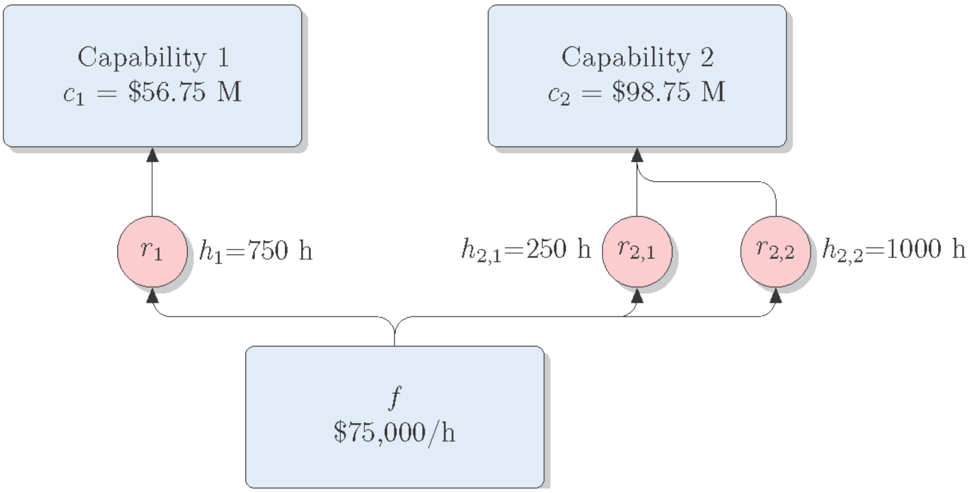

Figure 6-4: Example 2 – Multiple Readiness Levels.

6.3.3 Different Resources

Given the force structure f described in previous example, suppose that Capability 1 and 2 require different combinations of the force structure's resources, labelled f_1 for Capability 1 and f_2 for Capability 2 (e.g., Capability 2 requires specialized radar and munitions that are not required by Capability 1). This situation is known as a *process view* within TDABC.

Suppose if only the combination of components required by Capability 1 were acquired, the force structure's capacity cost rate would be \$50,000 per hour. Likewise, if the combination of components required by Capability 2 were acquired, suppose the capacity cost rate would be \$75,000 per hour (as in the previous example). The relationship between capacity cost rate and capacity usage in this situation is shown in Figure 6-5.

The demand for different resources in Figure 6-5 is similar to the concept of peak-load capacity used with TDABC [5]; that is, given the force structure f has been acquired to provide Capability 1 and 2, the capacity cost rate associated with Capability 2 should account for the unused capacity associated with Capability 1. The capacity cost rates for f_1 and f_2 are then as follows:

$$\text{Capacity cost rate } f_1 = \frac{\$50{,}000 \text{ per hour} \cdot 750 \text{ hours}}{750 \text{ hours}} = \$50{,}000 \text{ per hour}$$

$$\text{Capacity cost rate } f_2 = \frac{\$75{,}000 \text{ per hour} \cdot 1250 \text{ hours} + \$25{,}000 \text{ per hour} \cdot 750 \text{ hours}}{1250 \text{ hours}} = \$90{,}000 \text{ per hour}$$

The first term in the numerator of the capacity cost rate for f_2 represents the consumption of capacity by Capability 2, and the second term represents the unused capacity by Capability 1.

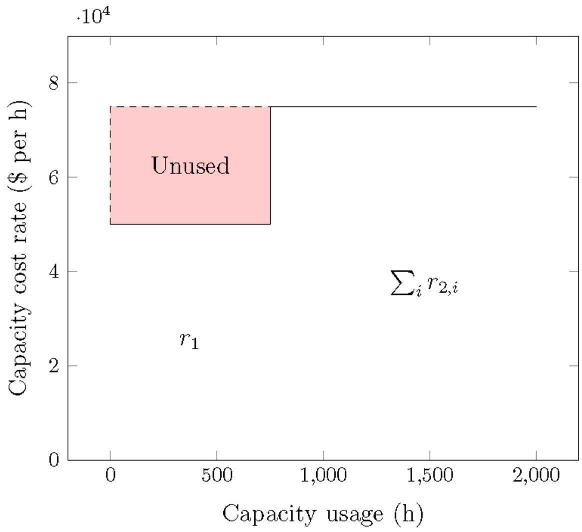

Figure 6-5: Example 3 – Relationship Between Capacity Cost Rate and Capacity Usage When There is Demand for Different Resources.

Given these capacity cost rates, and assuming the same annual readiness training costs as in the previous example, the cost of Capability 1 and 2 are calculated as follows and are shown in Figure 6-6.

$$c_1 = \$0.5\text{ M} + h_1 \cdot \frac{\$75{,}000}{\text{per hour}}$$

$$c_2 = \sum_{i=1}^{2} \left(\beta_i + h_{2,i} \cdot \frac{\$90{,}000}{\text{per hour}} \right)$$

As compared with the previous example, the cost of Capability 1 has decreased from $56.75 million to $38 million, and the cost of Capability 2 has increased from $98.75 million to $117.5 million. This is due to the decrease in the capacity cost rate associated with Capability 1 and that the unused force structure capacity within Capability 1 is being assigned to Capability 2, thus increasing its capacity cost rate. Since Capability 2 required the acquisition of specialized resources not required for Capability 1, these costs better reflect the actual cost of the capabilities.

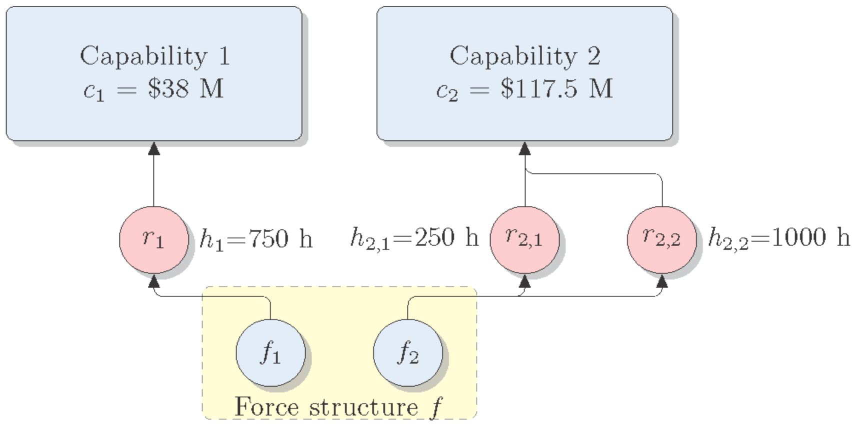

Figure 6-6: Example 3 – Different Resources.

6.3.4 Multiple Different Resources

The example shown in Figure 6-6 is relatively straightforward – one force structure that provides two capabilities, which each requires a different combination of the force structure's resources. In reality, force structures typically provide multiple capabilities, which each may require different combinations of the components.

Given the force structure *f* described in the previous example, suppose that it is decided that *f* will be used to provide a third capability, labelled Capability 3, which requires a different set of *f*'s components, labelled f_3, than Capability 1 and 2. Given the total allocated readiness training capacity for *f* is 2000 hours per year, it's decided that the number of hours used for Capability 2 high-level readiness training will be reduced from 1000 hours to 500 hours, and the difference will be used to perform readiness training for Capability 3. The cost of conducting 500 hours of high-level readiness training for Capability 2 is $2.5 million and the cost of conducting readiness training for Capability 3 is $4 million.

Similar to the previous example, suppose if only the combinations of components to provide the capabilities were acquired, then the capacity cost rates would be:

- If only the combination of components required to provide Capability 1 were acquired, the capacity cost rate for f_1 would be $50,000 per hour.
- If only the combination of components required to provide Capability 2 were acquired, the capacity cost rate for f_2 would be $75,000 per hour (e.g., Capability 2 requires specialized radar and munitions not required by Capability 1).
- If only the combination of components required to provide Capability 3 were acquired, the capacity cost rate f_3 would be $80,000 per hour (e.g., Capability 3 requires the specialized radar and munitions, plus additional software not required by Capability 1 or 2).

Similar to Figure 6-6, the relationship between the capacity cost rates and capacity usage is shown in Figure 6-7.

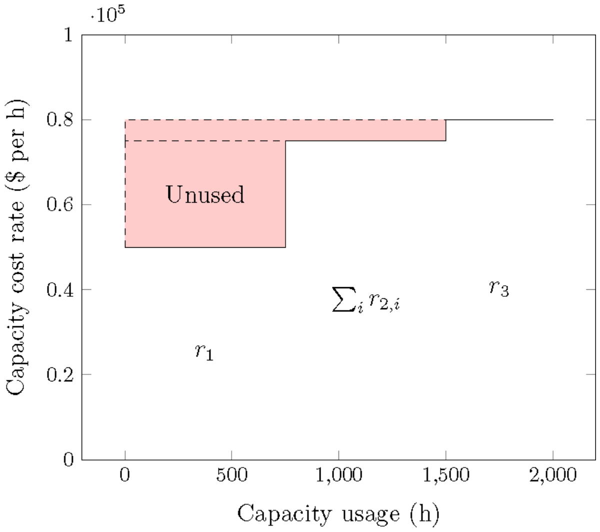

Figure 6-7: Example 4 – Relationship Between Capacity Cost Rate and Capacity Usage When There is Demand for Multiple Different Resources.

As in the previous example, the unused force structure capacity associated with Capability 1 and 2 should be accounted for. Three approaches are possible: first, assign the unused capacity to the capability with the next highest capacity cost rate (i.e., unused capacity in Capability 1 is assigned to Capability 2, unused capacity in Capability 2 is assigned to Capability 3); second, assign a portion of the unused capacity to the capability with the next highest capacity cost rate, where the portion is determined by the capacity usage; third, all unused capacity is assigned to the Capability with no unused capacity. The second option is preferred since a portion of the unused capacity in Capability 1 is used in Capability 2 and Capability 3 and likewise a portion in Capability 2 is used in Capability 3. The capacity cost rates for f_1, f_2, and f_3 are then as follows:

$$\text{Capacity cost rate } f_1 = \frac{\$50{,}000 \text{ per hour} \cdot 750 \text{ hours}}{750 \text{ hours}} = \$50{,}000 \text{ per hour}$$

$$\begin{aligned}\text{Capacity cost rate } f_2 &= \frac{\$75{,}000 \text{ per hour} \cdot 750 \text{ hours}}{750 \text{ hours}} + \frac{\$25{,}000 \text{ per hour} \cdot 750 \text{ hours} \cdot \dfrac{750 \text{ hours}}{750 \text{ hours} + 500 \text{ hours}}}{750 \text{ hours}} \\ &= \$90{,}000 \text{ per hour}\end{aligned}$$

$$\begin{aligned}\text{Capacity cost rate } f_3 &= \frac{\$80{,}000 \text{ per hour} \cdot 500 \text{ hours}}{500 \text{ hours}} + \frac{\$25{,}000 \text{ per hour} \cdot 750 \text{ hours} \cdot \dfrac{500 \text{ hours}}{750 \text{ hours} + 500 \text{ hours}}}{500 \text{ hours}} \\ &+ \frac{\$5{,}000 \text{ per hour} \cdot 1{,}500 \text{ hours}}{500 \text{ hours}} \\ &= \$110{,}000 \text{ per hour}\end{aligned}$$

The cost of the capabilities is calculated as follows and is shown in Figure 6-8.

$$c_1 = \$0.5\text{ M} + h_1 \cdot \frac{\$50{,}000}{\text{per hour}}$$

$$c_2 = \sum_{i=1}^{2} \left(\beta_i + h_{2,i} \cdot \frac{\$90{,}000}{\text{per hour}} \right)$$

$$c_1 = \$4\text{ M} + h_1 \cdot \frac{\$110{,}000}{\text{per hour}}$$

The cost of Capability 1 is unchanged as compared to the previous example; however, the cost of Capability 2 has decreased from \$112.5 million to \$72 million and the cost of Capability 3 is \$59 million. The total cost of the three capabilities is \$169 million, of which \$160 million is the force structures' EAC (less readiness training) and \$9.5 million is readiness training. The increase in the former, from \$150 million to \$160 million, is due to the additional kit required to provide Capability 3.

This example assumes that the resources required for each capability (i.e., f_1, f_2, and f_3) build upon one another. A force structure may exist such that this is not the case; that is, the components of a force structure required for some capabilities may be disjoint from those components required for other capabilities. In this case, for analytical purposes the force structure should be divided into multiple sub-force structures such that the sets of components required are not disjoint within each sub-force structure. The TDABC approach should then be applied to each sub-force structure.

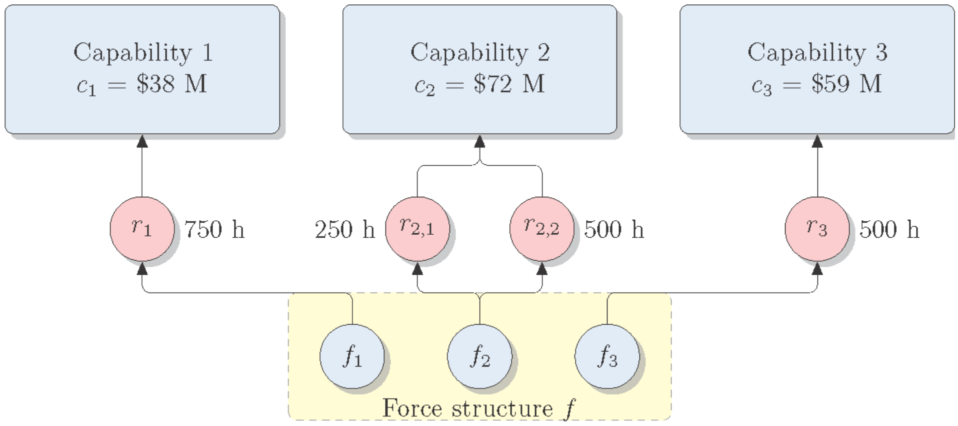

Figure 6-8: Example 4 – Multiple Different Resources.

6.3.5 Simultaneous Capacity Usage

Suppose that a force structure's capacity is used simultaneously for operations and readiness training. For example, a ship on its way to an operation may conduct its required readiness training prior to arrival. In this case, the cost of readiness training used in the capability cost calculations is the cost *if* the operations did not occur.

For example, suppose a force structure has a planned yearly capacity of 300 sea-days, a planned capacity of 200 sea-days for operations, and a planned capacity of 100 sea-days for readiness training. In addition, it is projected that 50 of the readiness sea-days will occur in-transit or during operations. The readiness cost used in the capability cost calculations is the cost of 100 sea-days – that is, the cost *if* the operations did not occur. In this way, the cost of capabilities remains independent of operations.

6.4 DISCUSSION

In this section, we present a discussion of implementation issues, data requirements, and how the output of this approach may be used within capability-based planning to inform resource allocation decisions.

6.4.1 Accuracy, Not Precision

The objective of the approach described in this report is to calculate a capability's strategic cost – that is, the calculated cost must be accurate but does not have to be precise. It is sufficient for the purposes of strategic decision-making to know a capability's cost to the first digit, to be close on the second, and follow with zeros thereafter. As a result, 'lite' measurement techniques, as opposed to those commonly used in industrial engineering [14], may be used to estimate the time required to perform activities. These 'lite' techniques include:

- Direct observation;
- Accumulating the time required to perform an activity several times and then calculate the average time;
- Interviewing or surveying employees;
- Utilize existing process maps; and
- Leverage time estimates from other areas within the organization or similar organizations.

6.4.2 Simplified Approach

A simplified approach to attributing a force structure's cost to capabilities is to base the attributions on the proportion of actual time used to conduct readiness training for the capabilities. This simplification skips the estimation of practical capacity and cost rates. A capability's cost is then calculated as:

$$\text{Capability cost} = \sum_{\substack{Fo \\ structure}} \frac{\text{Training time}}{\text{Total time}} \cdot \text{Force structure EAC}$$

where the total time is the total readiness training time and the force structure's EAC includes readiness training costs.

Kaplan and Anderson identified three reasons why this approach may be used. In terms of capability costing, they are as follows [5]:

- Once the force structure's EAC and estimates of how much time is used to train for the capabilities are known, the capability costs can be computed without estimating the practical capacity or capacity cost rate of each force structure;
- Decision-makers, in particular those in financial positions, may value having all costs assigned to capabilities; and
- Since there are no unused capacity costs, there are no questions about how to assign them.

Although this approach is simpler, it does have three drawbacks:

- First, since it skips the estimation of practical capacity, it does not signal when force structures are under or over capacity;
- Second, capability costs will be inflated if there is unused capacity; and
- Third, readiness training costs are not directly assigned to the capabilities' costs, and thus may be attributed incorrectly. Thus, there is a trade-off to be made between simplicity and accuracy.

6.4.3 Time Equations

Variability in how readiness training is conducted for a capability leads to variability in the capability's resource demands. Although describing resource demands at this more granular level increases the complexity of the model, it is important because, otherwise, the model will fail to capture the differences between different variations in demands.

When developing equations to calculate a capability's cost (i.e., time equations), Kaplan and Anderson suggest the following sequence [5]:

- Start where the most time is spent and cost is incurred, since accurate modelling of these processes will have the largest potential impact on the organization;
- Define the scope of the activity. Be clear about where an activity is initiated and concludes;
- For each activity, identify the most significant factor that effects resource consumption;
- If possible, use existing data rather than installing new data collection technologies. However, if key activities that consume a large percentage of total cost have data gaps, then it may be justified to invest in new data collection systems;
- Start simple and add more accuracy if required; and

- Engage operational personnel to help build and validate the model. The model is only as good as the organization perceives it to be.

6.4.4 Data Requirements

The data required to implement this approach may be clustered into two groups: *force structure related* and *capability related*.

- **Force structure related**
  - **Set of force structures**: A set of force structures, such as those identified by the Strategic Costing Model [1], [2] or those identified by a capability-based planning process, as described in Table 6-1. These resources provide the capabilities.
  - **Force structure EAC**: The total EAC of each force structure, as computed by a force structure costing model, less the EAC of the readiness training the force structure conducts.
  - **Force structure practical capacity**: The force structure planned capacity to conduct readiness training. This information may be extracted from the force structures' strategic planning documents.
  - **Force structure readiness levels**: The set of readiness levels that each force structure provides for each capability. In addition, the planned number of hours of training for each readiness level and the associated cost. This information may be extracted from the force structures' strategic planning documents.
- **Capability related**
  - **Capability taxonomy**: A taxonomy of capabilities, such as those identified in a capability-based planning process. The tier within the taxonomy to be costed should be that which is analysed in the capability-based planning process for importance and affluence/deficiency. Thus, not only will capability costing information be useful within force structure studies, but it will also useful within the higher-level defence planning process.
  - **Capability-to-force structure mapping**: A mapping of which force structures provide which capabilities. This information is captured within the capability-based planning process.

6.4.5 Integrating with Capability-Based Planning: A Canadian Example

The Canadian approach to capability-based planning [15] creates a large amount of data that is often difficult for decision-makers to comprehend. However, existing statistical techniques may be used to summarize the data to help decision-makers overcome this issue. For example, Rempel describes how dimensionality reduction and partition clustering can be applied to capability-based planning data to create visualizations that convey how important capabilities are in planning scenarios and how much operational capacity the planned force structures have to provide the capabilities [16]. An example of visualization is shown in Figure 6-9, where each blue circle represents a capability. Capabilities in the lower left are those that have low operational capacity and a low importance, whereas those in the upper right have a high operational capacity and a high importance across the planning scenarios.

The output of the TDABC based capability costing method described can be combined with information in the above figure. For example, Figure 6-10 shows the same information as Figure 6-9, and in addition uses the area of the circles to encode the capabilities' cost such that higher cost capabilities have larger circles. The example shows that the capabilities on the left (low importance and low/medium operational capacity) have a relative high cost as compared to the other capabilities. These capabilities may be candidates for divestment. Subsequently, their financial resources may be diverted to higher priority capabilities (e.g., those on the right side of the figure with high importance and low to medium operational capacity). Thus, combining this information together enables decision-makers to make evidence-based resource allocation decisions at the capability level.

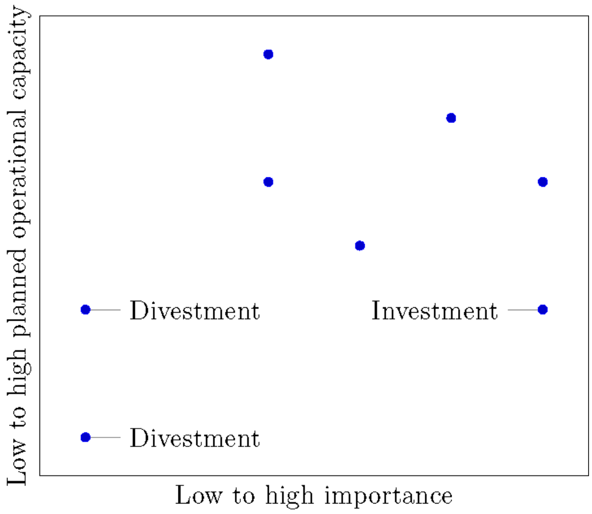

Figure 6-9: Capability Capacity *vs.* Importance. Each circle represents a capability.

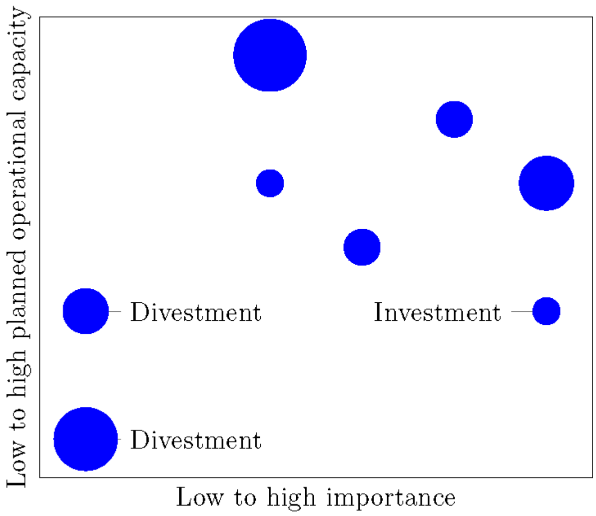

Figure 6-10: Capability Capacity *vs.* Importance. Each circle represents a capability and the size of each circle represents the capability's cost.

6.5 SUMMARY

In this chapter, we described how TDABC may be used to calculate the cost of capability. The method attributes force structure costs to capabilities based on the amount of readiness training the force structure conducts for the capabilities it provides. The cost of a capability is then the sum of the attributed costs plus the cost of readiness training. We presented five examples that highlight unique aspects of force structures and showed how these aspects are interpreted within issues commonly found in TDABC applications (i.e., departmental *vs*. process view, peak-load capacity, etc.). Lastly, we discussed several implementation issues and data requirements.

6.6 REFERENCES

[1] Chouinard, P., and Wood, I. (2007). *The Department of National Defence Strategic Cost Model: Development.* Defence Research and Development Canada.

[2] Solomon, B., Chouinard, P., and Kerzner, L. (2008). *The Department of National Defence Strategic Cost Model: Volume II – Theory and Emperics.* Defence Research and Development Canada.

[3] Kerzner, L., Chouinard, P., and Solomon, B. (2009). *The Department of National Defence Strategic Cost Model: Description and Documentation.* Defence Research and Development Canada.

[4] Department of National Defence and Canadian Armed Forces. (n.d.). *Search and Rescue Canada*. Retrieved December 16, 2013, from http://www.forces.gc.ca/en/operations-canada-north-america-current/sar-canada.page.

[5] Kaplan, R., and Anderson, S. (2007). *Time-driven activity-based costing: A simpler and more powerful path to higher profits.* Boston, Massachuetts: Harvard Business Press.

[6] Rempel, M. (2015). A time-driven approach to capability costing. Defence Research and Development Canada, DRDC-RDDC-2015-R179.

[7] Stout, D., and Propri, J. (2011). Implementing time-driven activity-based costing at a medium-sized electronics company. *Management Accounting Quarterly, 12*(3), pp. 1-11.

[8] Demeere, N., Stouthuysen, K., and Roodhooft, F. (2009). Time-driven activity-based costing in an outpatient clinic environment: Development, relevance, and managerial impact. *Health Policy, 92*, pp. 296-304.

[9] Kaplan, R., and Porter, M. (2011). The Big Idea: How to Solve the cost crisis in health care. *Harvard Business Review*, pp. 46-64.

[10] Pernot, E., Roodhooft, F., and van den Abbeele, A. (2007). Time-driven activity-based costing for inter-library services: A case study in a university. *The Journal of Academic Librarianship, 33*(5), pp. 551-560.

[11] Dalci, I., Tanis, V., and Kosan, L. (2010). Customer profitability analysis with time-driven activity-based costing. *International Journal of Comtemporary Hospitality Management, 22*(5), pp. 609-637.

[12] Hoozee, S., and Hansen, S. (2014). *A comparison of activity-based costing and time-driven activity-based costing.*

[13] Voith, M. (2001). Military readiness. *The army doctraine and training bulletin, 4*(2), pp. 41-48.

[14] Konz, S. (2007). Time standards. In *Handbook of Industrial Engineering*, pp. 1391-1408. John Wiley & Sons, Inc.

[15] Rempel, M. (2010). *An Overview of the Defence Second Generation Capability-Based Planning Analytical Process.* Defence Research and Development Canada.

[16] Rempel, M. (2014). Using visualization to support investment and divestment decisions in the Canadian Armed Forces. *Journal of Data Science, 12*(3), pp. 477-494.

Chapter 7 – CONCLUSION

A summary of this report's conclusions are:

- While it is important to define risk and develop quantitative models to assess it, more important and arguably the biggest cause of risk is the human component. The reference case model allows for our biases to be reduced somewhat as long as we are truthful in the reference class we choose, and then thorough in our application. Failure to do either of these effectively will mean that the *status quo* will be maintained, that quantitative models will continue to provide us information that a project is affordable while history shows that it is not.
- Seven topics related to a force structure's cost risk are identified that, if possible, should be included in a costing study. For each topic that can be addressed using visualization, example visualizations were presented. Each example was discussed in the context of a risk visualization framework and best practices to visually encode data.
- The quality of the cost risk visualizations ultimately is determined by the ability of an analyst to turn the concepts discussed into reality. Armed with the visualization guidelines and risk visualization framework, an analyst has the necessary tools to create simple and effective visualizations that ease the communication a force structure's cost risks with decision-makers.
- We described how Time-Driven Activity-Based Costing may be used to calculate the cost of capability. The method attributes force structure costs to capabilities, based on the amount of readiness training the force structure conducts for the capabilities it provides. The cost of a capability is then the sum of the attributed costs plus the cost of readiness training. We presented five examples that highlight unique aspects of force structures and showed how these aspects are interpreted within issues commonly found in TDABC applications (i.e., departmental *vs.* process view, peak-load capacity, etc.).

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's References	3. Further Reference	4. Security Classification of Document
	STO-TR-SAS-092 AC/323(SAS-092)TP/875	ISBN 978-92-837-2199-4	PUBLIC RELEASE

5. Originator

Science and Technology Organization
North Atlantic Treaty Organization
BP 25, F-92201 Neuilly-sur-Seine Cedex, France

6. Title

Costing Support to Force Structure Studies

7. Presented at/Sponsored by

Final Report of SAS-092.

8. Author(s)/Editor(s)	9. Date
Multiple	July 2020

10. Author's/Editor's Address	11. Pages
Multiple	98

12. Distribution Statement

There are no restrictions on the distribution of this document. Information about the availability of this and other STO unclassified publications is given on the back cover.

13. Keywords/Descriptors

Capability costing; Cost escalation; Cost model; Cost risk; Costing; Defence specific inflation Force structure

14. Abstract

SAS-092 ran from 2011 to 2015 with the purpose of developing "a common methodology for Capability Costing and Cost Analysis as part of Force Structure Studies." Cost analysis for force structure studies are hugely beneficial to decision makers who have the job of making best use of limited resources to achieve defence aims.

The panel aimed to provide guidance for nations whose force structure costing capability was not as mature as those nations participating, while at the same time making a scientific contribution to this field.

NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

BP 25
F-92201 NEUILLY-SUR-SEINE CEDEX • FRANCE
Télécopie 0(1)55.61.22.99 • E-mail mailbox@cso.nato.int

DIFFUSION DES PUBLICATIONS
STO NON CLASSIFIEES

Les publications de l'AGARD, de la RTO et de la STO peuvent parfois être obtenues auprès des centres nationaux de distribution indiqués ci-dessous. Si vous souhaitez recevoir toutes les publications de la STO, ou simplement celles qui concernent certains Panels, vous pouvez demander d'être inclus soit à titre personnel, soit au nom de votre organisation, sur la liste d'envoi.

Les publications de la STO, de la RTO et de l'AGARD sont également en vente auprès des agences de vente indiquées ci-dessous.

Les demandes de documents STO, RTO ou AGARD doivent comporter la dénomination « STO », « RTO » ou « AGARD » selon le cas, suivi du numéro de série. Des informations analogues, telles que le titre est la date de publication sont souhaitables.

Si vous souhaitez recevoir une notification électronique de la disponibilité des rapports de la STO au fur et à mesure de leur publication, vous pouvez consulter notre site Web (http://www.sto.nato.int/) et vous abonner à ce service.

CENTRES DE DIFFUSION NATIONAUX

ALLEMAGNE
Streitkräfteamt / Abteilung III
Fachinformationszentrum der Bundeswehr (FIZBw)
Gorch-Fock-Straße 7, D-53229 Bonn

BELGIQUE
Royal High Institute for Defence – KHID/IRSD/RHID
Management of Scientific & Technological Research for Defence, National STO Coordinator
Royal Military Academy – Campus Renaissance
Renaissancelaan 30, 1000 Bruxelles

BULGARIE
Ministry of Defence
Defence Institute "Prof. Tsvetan Lazarov"
"Tsvetan Lazarov" bul no.2
1592 Sofia

CANADA
DGSIST 2
Recherche et développement pour la défense Canada
60 Moodie Drive (7N-1-F20)
Ottawa, Ontario K1A 0K2

DANEMARK
Danish Acquisition and Logistics Organization (DALO)
Lautrupbjerg 1-5
2750 Ballerup

ESPAGNE
Área de Cooperación Internacional en I+D
SDGPLATIN (DGAM)
C/ Arturo Soria 289
28033 Madrid

ESTONIE
Estonian National Defence College
Centre for Applied Research
Riia str 12
Tartu 51013

ETATS-UNIS
Defense Technical Information Center
8725 John J. Kingman Road
Fort Belvoir, VA 22060-6218

FRANCE
O.N.E.R.A. (ISP)
29, Avenue de la Division Leclerc
BP 72
92322 Châtillon Cedex

GRECE (Correspondant)
Defence Industry & Research General Directorate, Research Directorate
Fakinos Base Camp, S.T.G. 1020
Holargos, Athens

HONGRIE
Hungarian Ministry of Defence
Development and Logistics Agency
P.O.B. 25
H-1885 Budapest

ITALIE
Ten Col Renato NARO
Capo servizio Gestione della Conoscenza
F. Baracca Military Airport "Comparto A"
Via di Centocelle, 301
00175, Rome

LUXEMBOURG
Voir Belgique

NORVEGE
Norwegian Defence Research Establishment
Attn: Biblioteket
P.O. Box 25
NO-2007 Kjeller

PAYS-BAS
Royal Netherlands Military Academy Library
P.O. Box 90.002
4800 PA Breda

POLOGNE
Centralna Biblioteka Wojskowa
ul. Ostrobramska 109
04-041 Warszawa

PORTUGAL
Estado Maior da Força Aérea
SDFA – Centro de Documentação
Alfragide
P-2720 Amadora

REPUBLIQUE TCHEQUE
Vojenský technický ústav s.p.
CZ Distribution Information Centre
Mladoboleslavská 944
PO Box 18
197 06 Praha 9

ROUMANIE
Romanian National Distribution Centre
Armaments Department
9-11, Drumul Taberei Street
Sector 6
061353 Bucharest

ROYAUME-UNI
Dstl Records Centre
Rm G02, ISAT F, Building 5
Dstl Porton Down
Salisbury SP4 0JQ

SLOVAQUIE
Akadémia ozbrojených síl gen. M.R. Štefánika, Distribučné a informačné stredisko STO
Demänová 393
031 01 Liptovský Mikuláš 1

SLOVENIE
Ministry of Defence
Central Registry for EU & NATO
Vojkova 55
1000 Ljubljana

TURQUIE
Milli Savunma Bakanlığı (MSB)
ARGE ve Teknoloji Dairesi Başkanlığı
06650 Bakanliklar – Ankara

AGENCES DE VENTE

The British Library Document Supply Centre
Boston Spa, Wetherby
West Yorkshire LS23 7BQ
ROYAUME-UNI

Canada Institute for Scientific and Technical Information (CISTI)
National Research Council Acquisitions
Montreal Road, Building M-55
Ottawa, Ontario K1A 0S2
CANADA

Les demandes de documents STO, RTO ou AGARD doivent comporter la dénomination « STO », « RTO » ou « AGARD » selon le cas, suivie du numéro de série (par exemple AGARD-AG-315). Des informations analogues, telles que le titre et la date de publication sont souhaitables. Des références bibliographiques complètes ainsi que des résumés des publications STO, RTO et AGARD figurent dans le « NTIS Publications Database » (http://www.ntis.gov).

NORTH ATLANTIC TREATY ORGANIZATION

BP 25
F-92201 NEUILLY-SUR-SEINE CEDEX • FRANCE
Télécopie 0(1)55.61.22.99 • E-mail mailbox@cso.nato.int

SCIENCE AND TECHNOLOGY ORGANIZATION

DISTRIBUTION OF UNCLASSIFIED STO PUBLICATIONS

AGARD, RTO & STO publications are sometimes available from the National Distribution Centres listed below. If you wish to receive all STO reports, or just those relating to one or more specific STO Panels, they may be willing to include you (or your Organisation) in their distribution.

STO, RTO and AGARD reports may also be purchased from the Sales Agencies listed below.

Requests for STO, RTO or AGARD documents should include the word 'STO', 'RTO' or 'AGARD', as appropriate, followed by the serial number. Collateral information such as title and publication date is desirable.

If you wish to receive electronic notification of STO reports as they are published, please visit our website (http://www.sto.nato.int/) from where you can register for this service.

NATIONAL DISTRIBUTION CENTRES

BELGIUM
Royal High Institute for Defence – KHID/IRSD/RHID
Management of Scientific & Technological Research for Defence, National STO Coordinator
Royal Military Academy – Campus Renaissance
Renaissancelaan 30
1000 Brussels

BULGARIA
Ministry of Defence
Defence Institute "Prof. Tsvetan Lazarov"
"Tsvetan Lazarov" bul no.2
1592 Sofia

CANADA
DSTKIM 2
Defence Research and Development Canada
60 Moodie Drive (7N-1-F20)
Ottawa, Ontario K1A 0K2

CZECH REPUBLIC
Vojenský technický ústav s.p.
CZ Distribution Information Centre
Mladoboleslavská 944
PO Box 18
197 06 Praha 9

DENMARK
Danish Acquisition and Logistics Organization (DALO)
Lautrupbjerg 1-5
2750 Ballerup

ESTONIA
Estonian National Defence College
Centre for Applied Research
Riia str 12
Tartu 51013

FRANCE
O.N.E.R.A. (ISP)
29, Avenue de la Division Leclerc – BP 72
92322 Châtillon Cedex

GERMANY
Streitkräfteamt / Abteilung III
Fachinformationszentrum der Bundeswehr (FIZBw)
Gorch-Fock-Straße 7
D-53229 Bonn

GREECE (Point of Contact)
Defence Industry & Research General Directorate, Research Directorate
Fakinos Base Camp, S.T.G. 1020
Holargos, Athens

HUNGARY
Hungarian Ministry of Defence
Development and Logistics Agency
P.O.B. 25
H-1885 Budapest

ITALY
Ten Col Renato NARO
Capo servizio Gestione della Conoscenza
F. Baracca Military Airport "Comparto A"
Via di Centocelle, 301
00175, Rome

LUXEMBOURG
See Belgium

NETHERLANDS
Royal Netherlands Military Academy Library
P.O. Box 90.002
4800 PA Breda

NORWAY
Norwegian Defence Research Establishment, Attn: Biblioteket
P.O. Box 25
NO-2007 Kjeller

POLAND
Centralna Biblioteka Wojskowa
ul. Ostrobramska 109
04-041 Warszawa

PORTUGAL
Estado Maior da Força Aérea
SDFA – Centro de Documentação
Alfragide
P-2720 Amadora

ROMANIA
Romanian National Distribution Centre
Armaments Department
9-11, Drumul Taberei Street
Sector 6
061353 Bucharest

SLOVAKIA
Akadémia ozbrojených síl gen M.R. Štefánika, Distribučné a informačné stredisko STO
Demänová 393
031 01 Liptovský Mikuláš 1

SLOVENIA
Ministry of Defence
Central Registry for EU & NATO
Vojkova 55
1000 Ljubljana

SPAIN
Área de Cooperación Internacional en I+D
SDGPLATIN (DGAM)
C/ Arturo Soria 289
28033 Madrid

TURKEY
Milli Savunma Bakanlığı (MSB)
ARGE ve Teknoloji Dairesi Başkanlığı
06650 Bakanliklar – Ankara

UNITED KINGDOM
Dstl Records Centre
Rm G02, ISAT F, Building 5
Dstl Porton Down, Salisbury SP4 0JQ

UNITED STATES
Defense Technical Information Center
8725 John J. Kingman Road
Fort Belvoir, VA 22060-6218

SALES AGENCIES

The British Library Document Supply Centre
Boston Spa, Wetherby
West Yorkshire LS23 7BQ
UNITED KINGDOM

Canada Institute for Scientific and Technical Information (CISTI)
National Research Council Acquisitions
Montreal Road, Building M-55
Ottawa, Ontario K1A 0S2
CANADA

Requests for STO, RTO or AGARD documents should include the word 'STO', 'RTO' or 'AGARD', as appropriate, followed by the serial number (for example AGARD-AG-315). Collateral information such as title and publication date is desirable. Full bibliographical references and abstracts of STO, RTO and AGARD publications are given in "NTIS Publications Database" (http://www.ntis.gov).

ISBN 978-92-837-2199-4