ROUTLEDGE STUDIES IN DEFENCE AND PEACE ECONOMICS

Military Cost–Benefit Analysis

Theory and practice

Edited by
Francois Melese, Anke Richter, and
Binyam Solomon

ROUTLEDGE

Military Cost–Benefit Analysis

This is the first comprehensive book dedicated to military cost–benefit analysis. The aim is to help countries identify affordable defense capabilities that effectively counter security risks in uncertain and fiscally constrained environments. This volume offers several new practical tools designed to guide defense investments (and divestments), combined with a selection of real-world applications.

The widespread employment of cost–benefit analysis offers a unique opportunity to transform legacy defense forces into efficient, effective, and accountable twenty-first-century organizations. A synthesis of economics, statistics, and decision theory, cost–benefit analysis is currently used in a wide range of defense applications in countries around the world: i) to shape national security strategy, ii) to set acquisition policy, and iii) to inform critical investments in people, equipment, infrastructure, services, and supplies. As sovereign debt challenges squeeze national budgets, and emerging threats disrupt traditional notions of security, this volume offers valuable tools to navigate the political landscape, meet calls for fiscal accountability, and boost the effectiveness of defense investments to help guarantee future peace and stability.

A valuable resource for scholars, practitioners, students, and experts, this book offers a comprehensive overview of military cost–benefit analysis that will appeal to anyone interested or involved in improving national security. It should also be of general interest to public officials responsible for major programs, projects or policies.

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"At a time when government budgets and public sector procurement are under immense pressure globally, it is imperative that practitioners and students alike fully understand the appropriate techniques available to properly evaluate such procurement in the interests of effective decision-making. This book makes a unique contribution in this regard providing, for the first time, an accessible handbook designed to meet this objective which focuses on the military sector where some of the most difficult decisions are currently having to be made. Both students and practitioners in the military sector will find this book essential reading and the ideas contained here will also resonate with those working in or studying other parts of the public sector."

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Theory and practice

Edited by Francois Melese, Anke Richter, and Binyam Solomon

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Preface

This edited volume should appeal to anyone interested or actively involved in improving national security. It should also be of general interest to those responsible for major government programs, projects or policies. A valuable resource for scholars and practitioners, novices and experts alike, this book offers a comprehensive overview of military cost–benefit analysis (CBA). The goal is to help countries identify affordable defense capabilities that effectively counter security risks, in fiscally constrained environments.

The book consists of five parts: I) Introduction and problem formulation; II) Measuring costs and future funding; III) Measuring effectiveness; IV) New approaches to military cost–benefit analysis; and V) Selected applications. The seventeen chapters that make up these five parts showcase a diversity of international experts with both theoretical and hands-on experience. Lifting the veil on military CBA, this volume offers several new practical tools designed to guide defense investments (and divestments), combined with a selection of real-world applications.

Widespread employment of CBA offers a unique opportunity to transform legacy defense forces into efficient, effective, and accountable twenty-first-century organizations. A synthesis of economics, management science, statistics and decision theory, CBA is currently used in a wide range of defense applications in countries around the world: i) to shape national security strategy, ii) to set acquisition policy, and iii) to inform critical investments in people, equipment, infrastructure, services and supplies. As sovereign debt challenges squeeze national budgets, and emerging threats disrupt traditional notions of security, this volume offers valuable tools to navigate the political landscape, meet calls for fiscal accountability, and boost the effectiveness of defense investments to help guarantee future peace and stability.

Abbreviations

ABC	activity based costing
ACAS	airlift cycle analysis spreadsheet
ACF	autocorrelation function
ADF	augmented Dickey–Fuller
ADF	Australian Defense Force
AFB	air force base
AFM	airlift flow model
AFSAA	air force studies and analysis agency
AIMP	aurora incremental modernization program
ALM	airlift loading model
AMC	Air Mobility Command
AMOS	air mobility operations model
AoA	analysis of alternatives
APC	armored personnel carriers
ARDL	autoregressive distributive lag
ARIMA	autoregressive integrated moving average
AVF	all-volunteer force
BCA	business case analysis
BLS	Bureau of Labor Statistics
BRAC	base realignment and closure
BSC	balanced scorecard
CAF	Canadian armed forces
CAG	Comptroller and Auditor General
CAIG	Cost Analysis Improvement Group
CAIV	cost as an independent variable
CAPE	cost assessment and program evaluation (formerly PA&E)
CARD	cost analysis requirements description
CBA	cost–benefit analysis
CBO	Congressional Budget Office
CBP	capability based planning
CBS	cost breakdown structure
CC	conventional campaign
CCDR	contractor cost data reports

CEA	cost-effectiveness analysis
CER	cost estimating relationships
CES	cost element structure
CFDS	Canada first defence strategy
CFOI	census of fatal occupational injuries
COCOMO	constructive cost model
COEA	cost and operational effectiveness analysis
CORA	Centre for Operations Research and Analysis
CORE	cost-oriented resource estimating
CPS	current population survey
CRAF	civil reserve air fleet
CSIS	Center for Strategic and International Studies
CSS	combat service support
C-X	cargo-experimental
DAB	defense acquisition board
DACIMS	defense acquisition automated cost information system
DAES	defense acquisition executive summaries
DAMIR	defense acquisition management information retrieval
DAS	defense acquisition system
DASA	Defense Atomic Support Agency
DAU	Defense Acquisition University
DCARC	Defense Cost and Resource Center
DFARS	defense federal acquisition regulation supplement
DMDC	Defense Manpower Data Center
DND	Department of National Defence
DoD	Department of Defense
DOT	Department of Transportation
DPS	defense policy statement
ECCM	electronic counter-countermeasures
ECM	electronic counter-measures
EDA	European Defence Agency
EEoA	economic evaluation of alternatives
EIBA	European International Business Academy
EMD	engineering and manufacturing development
EPA	Environmental Protection Agency
ESBM	enhanced scenario-based method
EVMS	earned value management system
FAA	Federal Aviation Administration
FAR	federal acquisition regulation
FDI	foreign direct investment
FFRDC	federally funded research and development center
FLIR	forward looking imaging infra-red
FMTV	family of medium tactical vehicles
FO	fiber-optic
FPA	focal plane array

FV	future value
FY	fiscal year
FYDP	future year defense plan
GAO	Government Accountability Office
GDF	guidance for the development of the force
GDP	gross domestic product
GMOD	German Ministry Of Defence
GSA	general services administration
HALE	high altitude long endurance
HMMWV	high-mobility, multipurpose wheeled vehicle
ICEAA	International Cost Estimating and Analysis Association
IDA	Institute for Defense Analyses
IEDS	improvised explosive devices
IEP	Institute for Economics and Peace
IFB	invitation for bid
IIE	Institute of Industrial Engineers
IOC	initial operational capability
IRB	industrial regional benefit
IS	Islamic state
ISR	intelligence, surveillance and reconnaissance
IW	irregular warfare
JCIDS	joint capabilities integration and development system
JCTD	joint capability technology demonstration
JPG	joint programming guidance
JROC	Joint Requirements Oversight Council
KVA	knowledge value added
LBR	laser beam-riding
LCAC	landing craft
LCC	life cycle cost
LCTA	lowest cost technically acceptable
LMI	logistics management institute
LPD	landing platform dock
LRC	lesser regional contingency
MADM	multi-attribute decision-making
MAIS	major acquisition information system
MANET	mobile ad hoc network
MASS	mobility analysis support system
MAUT	multi-attribute utility theory
MCDM	multi-criteria decision-making
MCO	major combat operation
MDAP	major defense acquisition projects
ME	military expenditures
MEO	most efficient organization
MHE	materiel-handling equipment
MM	man-months

MoD	Ministry of Defence
MODM	multi-objective decision-making
MoE	measure of effectiveness
MOG	maximum on ground
MRC	major regional contingency
MRS BURU	mobility requirements study bottom up review update
MRS	mobility requirements study
MRTS	marginal rate of technical substitution
MSHA	Mine Safety and Health Administration
MTBF	mean time between failure
MTM/D	million ton-miles per day
MTTR	mean time to repair
NAO	National Audit Office
NATO	North Atlantic Treaty Organization
NDAA	non-developmental airlift aircraft
NGO	non-government organization
NM	nautical mile
NPV	net present value
NZDF	New Zealand Defense Force
O&M	operations and maintenance
O&S	operations and support
OECD	Organisation for Economic Co-Operation and Development
OLS	ordinary least squares
OMB	Office of Management and Budget
ONS	Office for National Statistics
OSD	Office of the Secretary of Defense
OT&E	operational test and evaluation
OUSD (A&T)	Office of the Under Secretary of Defense (Acquisition and Technology)
PA&E	program analysis and evaluation (now renamed CAPE)
PAA	primary authorized aircraft
PAA	program alignment architecture
PACF	partial autocorrelation function
PALYS	protection-adjusted life years
PAX	passengers
PBD	program budget decision
PCA	principal component analysis
PDM	programmed depot maintenance
PEM	program element monitors
PFC	Privates First Class
PGI	procedures, guidance, and information
POM	program objectives memorandum
PPBE	planning, programming, budgeting and execution
PPBES	planning, programming, budgeting, and execution system
PPBS	planning, programming, and budgeting system

PV	present value
PVA	present value analysis
PWS	performance work statement
QALYS	quality measures of healthcare based on quality-adjusted life years
QDR	quadrennial defense review
R&D	research and development
RAB	resource accounting and budgeting
RAID	rapid aerostat initial deployment
RDT&E	research, development, testing, and evaluation
RFP	request for proposal
RFQ	request for quotation
RM&A	reliability, maintainability, and availability
ROI	return on investment
ROK	return-on-knowledge
RP	risk premium
RTO	(NATO) Research Technology Board
SAB	Scientific Advisory Board
SAFMA	strategic airlift force mix analysis
SAR	selected acquisition report
SAS	system analysis and studies
SC	Schwartz bayesian criterion
SCEA	Society of Cost Estimation and Analysis
SDC	(US Army Materiel Systems Analysis Activity's) sample data collection
SDR	strategic defense review
SecDef	Secretary of Defense
SIPRI	Stockholm International Peace Research Institute
SLEP	service life extension program
SMOD	Sweden Ministry of Defence
SoS	system-of-systems
SOW	statement of work
SSC	Strategic Systems Committee
SSEB	Source Selection Evaluation Board
SSSP	steady-state security posture
SUR	structural unexpended rate
TAI	total aircraft inventory
TCE	transaction cost economics
TOW	tube-launched, optically tracked, wire-guided
TPFDD	time-phased force deployment data
TQM	total quality management
TRL	technology readiness levels
TWV	tactical wheeled vehicles
UAV	unmanned aerial vehicle
USAF	United States Air Force

USDOD	Under Secretary of Defense
USN	United States Navy
USTRANSCOM	US Transportation Command
VAMOSC	visibility and management of operating and support costs
VSI	value of a statistical injury
VSL	value of statistical life
WBS	work breakdown structure
WEKA	the WEKA project (data mining in Java)
WMD	weapons of mass destruction
WSARA	Weapon Systems Acquisition Reform Act

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Part I

Introduction and problem formulation

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1 Introduction

Military cost–benefit analysis: theory and practice

Francois Melese, Anke Richter, and Binyam Solomon

1.1 Background

Military cost–benefit analysis (CBA) offers a vital tool to help guide governments through both stable and turbulent times. As countries struggle with the dual challenges of an uncertain defense environment and cloudy fiscal prospects, CBA offers a unique opportunity to transform defense forces into more efficient and effective twenty-first-century organizations.

Defense reforms typically involve politically charged debates over *investments* (in projects, programs, or policies) as well as contentious *divestment* decisions—from base realignment and closure (BRAC) to outsourcing and asset sales. A powerful contribution of CBA is to inform such complex and contentious decisions—carefully structuring the problem and capturing relevant costs and benefits of alternative courses of action. Lifting the veil on military CBA, this edited volume reveals several systematic quantitative approaches to assess defense investments (or divestments), combined with a selection of real-world applications.

The frameworks and methods discussed in the following chapters should appeal to anyone interested or actively involved in understanding and applying CBA to improve national security. These valuable approaches also have broader government-wide applications, especially in cases where it is difficult to monetize the benefits of a public project, program, or policy.

Unprecedented government spending to counter the global financial crisis has placed enormous pressure on public budgets. Combined with alarming demographics, many countries struggle to fulfill past promises to underwrite health care expenditures, social security payments, government pensions, and unemployment programs. As debt burdens grow to finance current operations, the risk of escalating interest payments threatens to crowd out vital future public spending. As the single largest discretionary item in many national budgets,[1] military expenditures make a tempting target. Especially vulnerable are military and civilian compensation (pay and benefits) and the purchase and operation of equipment, facilities, services, and supplies.

Anticipating future spending cuts, this book explores both conventional and unconventional approaches to contemporary defense decisions—from critical investments in facilities, equipment, and materiel to careful vendor selection to build, operate, and maintain those investments. Recognizing the value of systematic quantitative analysis, senior US Army leadership has "directed that any decisions involving Army resources be supported by a CBA."[2]

Faced with severe budget cuts and an uncertain threat environment, defense officials around the world confront urgent decisions on whether to approve specific *projects* (e.g. infrastructure—military housing; training, and maintenance facilities) or *programs* (e.g. weapon systems—unmanned aerial vehicles (UAVs), armored personnel carriers (APCs), cyber defense). Military CBA offers a valuable set of analytical tools to increase the transparency, efficiency, and effectiveness of critical defense decisions.

A synthesis of economics, management science, statistics, and decision theory, military CBA is currently used in a wide range of defense applications in countries around the world: i) to shape national security strategy, ii) to set acquisition policy, and iii) to inform critical investments in people, equipment, infrastructure, services, and supplies. This edited volume offers a selection of carefully designed CBA approaches, and real-world applications, intended to help public officials identify affordable defense capabilities that effectively counter security risks in fiscally constrained environments.

1.2 A brief history of cost–benefit analysis

The French engineer Jules Dupuit (Dupuit 1844) is widely credited with an early concept of CBA called "economic accounting." The British economist Alfred Marshall (Marshall 1920) later developed formal concepts that contributed to the analytical foundations of CBA.[3] In a pioneering survey, Prest and Turvey indicate that as early as 1902 the US River and Harbor Act required the Army Corps of Engineers to report on the desirability of any project, taking into account both the cost and the amount of "commerce benefited" (Prest and Turvey 1965). Widespread application of CBA in the United States is generally attributed to the 1936 Federal Navigation (Flood Control) Act. This required the Army Corps of Engineers to carry out projects to improve waterways when "the benefits to whomsoever they may accrue are in excess of the estimated costs" (Prest and Turvey 1965).

At the heart of CBA is the economists' concept of "allocative efficiency," in which resources are deployed to their highest valued use to maximize social welfare. A related and intuitively appealing definition called "Pareto efficiency" underpins CBA. An allocation is Pareto-efficient if no alternative allocation can make at least one person better off without making someone else worse off (Pareto 1909).

The link between allocations that yield maximum net benefits in CBA and Pareto efficiency is straightforward: If a public policy, program, or project has positive net benefits, then it is possible to find a set of transfers (side payments) that make at least one person better off without making anyone else worse off. Unfortunately, transfers necessary to achieve Pareto efficiency are difficult to

implement in practice. Therefore, out of practical necessity, CBA relies on a related decision rule called the Kaldor–Hicks criterion (Kaldor 1939; Hicks 1940). This decision rule states that a public policy, program, or project should be adopted, if and only if gainers could potentially fully compensate losers, and still be better off.[4]

Application of this decision rule is relatively straightforward:[5] Adopt all projects that have positive net benefits.[6] An important caveat is that the Kaldor–Hicks criterion only applies when costs and benefits can be monetized. Given the prevalence of non-monetary benefits in national defense, this poses a serious challenge for the security sector.

The growing interest in CBA after WWII is often attributed to rapid developments in operations research and systems analysis—techniques that helped win the war by combining economics, statistics, and decision theory. Following the allied victory, Project RAND (launched in 1946 by the Army Air Corps) received government funding to maintain scientific expertise developed in WWII and to conduct independent and objective research in national security.

A key contribution of RAND's research was "systems analysis" pioneered by Ed Paxson and advanced by Charles Hitch who in 1948 founded RAND's Economics Division. Whereas operations research had a more immediate, wartime focus (e.g. finding the best short-run solution to a military mission, given a restricted set of equipment, etc.), systems analysis was more future-oriented, focused on finding the optimal mix of doctrine, forces and equipment necessary to accomplish a military goal at the lowest possible cost (or alternatively, for a given budget, to find the optimal mix that maximizes defense capabilities).

Working at RAND in the immediate post-war era, Hitch teamed up with another economist, Roland McKean, to publish a pioneering text entitled *The Economics of Defense in the Nuclear Age* (Hitch and McKean 1960). The authors emphasized two main ways in which military CBA can be applied: i) to guide defense *policy* (i.e. the allocation of resources between major missions or military goals) and ii) to guide defense *investments* (i.e. choices between alternative projects or programs to achieve a given mission or goal). A significant challenge in applying CBA to defense decisions is the complex and often controversial task of measuring "benefits."

At the highest national strategic level, "benefits" of a specific defense policy[7] might be measured in terms of its impact on long-term economic growth, peace, and prosperity—all key contributors to social welfare. For example, suppose resource costs to achieve specific military goals are viewed as insurance payments against hazardous states of the world. Suppose further that defense policy decisions that achieve specific military goals reduce risk premiums associated with domestic and foreign direct investment (FDI). Empirical evidence suggests that FDI boosts economic growth and in turn contributes to peace and prosperity.[8] In this example, high-level defense decisions could ideally be made with the aim of increasing social welfare by encouraging investment, boosting GDP, and thereby generating a virtuous cycle of peace and prosperity.

In reality, this high-level effort to capture monetary benefits of defense policy as growth in GDP is rarely explored.[9] Instead, it typically gives way to a more

familiar perspective that makes up the bulk of chapters in this edited volume—where non-monetary "measures of effectiveness" (MoEs) of a policy, project or program substitute for monetary benefits.

Denied the opportunity to conduct controlled experiments or full-scale independent field tests to evaluate alternative policies, projects or programs, military officials and analysts are forced to resort to "proxy" variables. These include criteria and characteristics that reflect multiple objectives and that describe essential features of the alternatives being analyzed.[10] When benefits cannot be monetized, the terms "systems analysis" or "cost-effectiveness analysis" (CEA) are often used to describe military CBA.[11]

A related literature, alternately called multi-criteria decision-making (MCDM) or multi-objective decision-making (MODM), rapidly evolved after WWII to address the challenge of measuring non-monetary benefits of defense investments. The reader is encouraged to explore this literature for details on competing benefit measurement strategies, some of which are discussed in this volume. These measures have been in continuous development since the adoption of systems analysis by the US Department of Defense in the early 1960s.[12]

Following his election as President in 1960, John F. Kennedy appointed Robert McNamara Secretary of Defense. McNamara subsequently hired Charles Hitch as Comptroller to implement the Planning, Programming, and Budgeting System (PPBS) that Hitch had earlier helped develop at RAND. An output-oriented budgeting framework, PPBS relies heavily on systems analysis, or military CBA, to build a defense budget.

Prior to Hitch's tenure in the Office of Secretary of Defense, US defense budgets were largely based on the services' (Army, Navy, Air Force) proposals for annual incremental increases in inputs or "appropriation" categories (military personnel, procurement, operations and maintenance, military construction, etc.), often with little or no clear connection to defense outputs, joint missions, or national security goals. Having successfully employed a variant of PPBS called "program budgeting" as CEO of Ford Motor Company, McNamara recognized the value of building a defense budget that focuses on outputs (benefits) as well as costs.

The major innovation of PPBS is "programming," which bridges the gap between long-term military planning goals and short-term civilian budget realities. Designed as a constrained optimization underpinned by systems analysis, the "programming" phase was intended to produce a cost-effective mix of forces to maximize national security subject to funding constraints.[13]

Under certain conditions, the optimal allocation of a budget across various inputs (e.g. defense resources) that contribute to a common goal (i.e. increasing national security) requires the marginal contribution of each input towards that goal, for a given incremental cost, to be the same for any input. Since this decision rule is independent of the units in which the goal is measured, in principle it provides a valid test for allocative efficiency, satisfies the condition for Pareto optimality, and guarantees the most effective use of a defense budget.[14]

To implement PPBS, Hitch hired a RAND colleague, Dr Alain Enthoven, as Deputy Comptroller for Systems Analysis. In 1965, the impact of military CBA

was reinforced when Dr Robert Anthony of the Harvard Business School replaced Hitch as Comptroller and elevated Enthoven's position to Assistant Secretary of Defense for Systems Analysis.[15] Throughout his tenure, Secretary McNamara consistently applied systems analysis to evaluate policy, project and program proposals from the military services and to build defense budgets submitted to the Congress.[16] Military CBA continues to provide an analytical foundation that guides PPBS decisions in the United States and in countries around the world.

It is clear that politics influences defense decisions. It is also true that public officials can manipulate CBA for their own personal strategic interests. Politicians likely win more votes highlighting a program's benefits and downplaying its costs, and public administrators may be similarly rewarded. While it is clear pork-barrel politics often plays an important role in defense decisions, this book attempts to take the high road. It encourages the application of military CBA with a strict focus on national security interests.[17]

While employment, income distribution, and regional impacts of defense investment decisions often play a role in political decisions, a clean CBA can inform the process by revealing the true (opportunity) cost of decisions that drift too far from the goal of making the best use of scarce resources for the security of the country. Ideally, a carefully constructed military CBA focused strictly on national security concerns could be used to inform voters and counter special interest lobbying and rent-seeking that often leads defense firms to inefficiently spread production across key voting districts to promote their programs.[18]

A risk for any military CBA is that benefit and cost estimates might be strategically manipulated by self-interested agencies or individual decision-makers.[19] As Robert Haveman and others have pointed out, politicians facing difficult re-election tend to prefer projects that concentrate benefits on particular interest groups that offer them support, and to camouflage or defer costs, or to spread them widely across the population (Haveman 1976). Fortunately, as nations around the world embrace civilian control of the military, and citizens insist on greater accountability (including tighter linkages between budgets and security), an increased premium is placed on transparency in defense decisions.

While politics still dominates major defense decisions, the importance of military CBA rises alongside growing demands for transparency and accountability.[20] Costly defense procurement scandals reinforce the need for objective CBA approaches to improve transparency in vendor selection decisions.[21] Meanwhile, painful recovery from the global financial crisis,[22] combined with emergent threats, fuel public demand to carefully apply tools such as military CBA to build efficient, effective, and accountable security forces.

1.3 Outline

This edited volume reveals how military CBA can reduce budget pressures and improve defense decisions that contribute to national security. The dual purpose of CBA is to encourage more efficient and effective allocation of society's scarce resources to increase social welfare.[23] Governments often employ CBA to rank

(mutually exclusive) portfolios of projects or programs. The typical CBA involves at least eight steps:

1 Identify key decision-makers (and other stakeholders) to clarify goals, objectives, preferences, and constraints (including realistic funding projections).
2 Carefully structure the problem and identify feasible alternatives that contribute to those goals/objectives and that satisfy the constraints.
3 Determine the relevant time horizon over which the CBA will be conducted and select an appropriate discount rate.
4 Estimate relevant time-phased costs of each alternative over the relevant period.
5 Forecast time-phased benefits that will accrue over the relevant period.[24] This edited volume offers alternative approaches to structure a military CBA when benefits cannot be monetized. If benefits can be monetized, then the project or program with the highest net present value (NPV) can be recommended.[25]
6 The sixth step is to recognize uncertainty and conduct sensitivity analyses to determine whether results change with changes in key parameters (costs, benefits, budgets, discount rates, etc.).[26]
7 The seventh step is to report the results of the analysis (rankings of projects, programs, etc., along with key assumptions).
8 The final step is to make well-informed recommendations.

These eight basic steps of a CBA are explored throughout the chapters of this edited volume. The book consists of seventeen chapters divided into five parts.

1.3.1 Part I: Introduction and problem formulation

This part includes the first four chapters. Chapter 1 which you are reading offers a broad overview and outline of the book. Chapter 2 entitled "Allocating national security resources" sets the strategic tone of the book through the lens of US global security concerns. The Honorable J. Gansler (former US Under Secretary of Defense for Acquisition, Technology and Logistics) and his co-author W. Lucyshyn discuss challenges of wide-ranging international threats, domestic budgetary restrictions, and ongoing acquisition problems—including questions about future capacity to support current acquisitions. Revealing a possible mismatch between the National Security Strategy and the PPBS process, the authors highlight the need for military CBA at national, departmental, and program levels to make sound resource allocation decisions.[27] They also stress the vital role played by CBA in the continual process of reassessment and innovation necessary to maintain critical linkages between resources and requirements and to guarantee effective forces in a dynamic security environment.

In Chapter 3, a prominent UK pioneer in defense economics, K. Hartley, and his Canadian senior defense scientist co-author B. Solomon (co-editor of this volume), confront the challenge of measuring defense outputs. While the economics approach discussed in "Measuring defense output: an economics

perspective" is difficult to operationalize into a set of clear and unambiguous policy precepts, it does provide an important framework to help evaluate the benefits of defense outputs and activities. Combining theory and practice, the chapter describes attempts to measure defense outputs in the United States, Australia, New Zealand, and the United Kingdom and other European nations. Later chapters in this book provide several practical methods to help address challenges posed by the authors.

While maintaining the strategic themes of Chapter 2 and recognizing measurement challenges discussed in Chapter 3, Chapter 4 by F. Melese offers a comprehensive set of military CBA approaches to structure public investment decisions. Entitled "The economic evaluation of alternatives," six approaches are introduced that address a significant weakness in many conventional military "analyses of alternatives" (AoAs).[28] Historically, while AoAs correctly focused on lifecycle costs and operational effectiveness to evaluate alternatives, "affordability" was an afterthought, at best only implicitly addressed in final stages of the analysis.[29] In sharp contrast, the economic evaluation of alternatives (EEoA) encourages analysts and decision-makers to include affordability explicitly and up front in structuring a military CBA. EEoA places taxpayers alongside warfighters in the defense decision-making process. This requires working with vendors to build proposals based on different funding (budget/affordability) scenarios.[30] The decision map in the concluding section of Chapter 4 offers a comprehensive guide for practitioners to help structure an EEoA.[31]

1.3.2 Part II: Measuring costs and future funding

This part consists of three chapters. Chapter 5 entitled "Cost analysis" focuses on the first of the three main components of an EEoA—costs, budgets, and benefits. D. Nussbaum, who served as the US Navy's chief cost analyst, and his co-author, Professor D. Angelis, discuss approaches to collect, analyze, and estimate costs of proposed projects, programs, or activities. A unique contribution of this chapter is the explicit recognition of "transaction costs."[32] These include measurement, monitoring, management, contracting, negotiation, and other costs associated with government procurement. Depending on the nature of the transaction, it is conceivable that transaction costs could overwhelm the production costs of the desired product or service. Ignoring transaction costs creates a serious risk of underestimating the total costs of a project, program, or activity. In fact, the absence of transaction cost considerations in military CBAs may help explain the prevalence of cost overruns that often negatively impact expected returns on defense investments. To help address current biases and improve cost estimates in military CBAs, the authors recommend incorporating transaction cost considerations into traditional production cost calculations.

Chapter 6 entitled "Advances in cost estimating: a demonstration of advanced machine leaning techniques for cost estimation" presents recent technical advancements in cost estimation. The standard methods to estimate costs of defense systems in early design phases discussed in Chapter 5 include costing

by analogy and parametric approaches. Analogy methods base the costs of new systems on historical costs of similar or "analogous" systems. The traditional approach is to ask subject matter experts to make subjective evaluations of differences between the new system and the old. This leads to the application of complexity factors to adjust the analogous (old) system's cost to produce an estimate for the new system. Rather than apply subjectively obtained complexity factors, an innovative proposal by Defence Research and Development Canada scientist B. Kaluzny explores the use of machine learning algorithms to estimate the costs of systems in early design phases. The author proposes a cost estimation by analogy approach that involves an agglomerative hierarchical cluster analysis and nonlinear optimization that requires limited subjective input. With limited information, traditional parametric approaches to cost estimation rely on basic statistical models to develop cost estimating relationships (CERs) to help identify major cost drivers. CERs can be as simple as a ratio or involve linear regression analysis of historical systems or subsystems. The author proposes a new parametric technique, the M-system of Quinlan (a combination of decision trees and linear regression models), for learning models that predict numeric values.

Having established the importance of treating affordability (or future funding constraints) up front in an EEoA, the challenge of forecasting long-term defense budgets is explored in Chapter 7. Colonel R. Fetterly and B. Solomon begin their chapter "Facing future funding realities: forecasting budgets beyond the future year defense plan" by highlighting the importance of strategic management methods, such as capabilities-based planning, to link existing military capabilities and force development goals to the future security environment. These strategic management approaches are coupled with a variety of forecasting models that take into account a nation's security threats, income, spillover effects of allies' defense posture, and competing demands for a limited public purse. The authors draw on data from a selection of NATO countries to develop several valuable budget forecasting models.

1.3.3 Part III: Measuring effectiveness

Chapters 8 and 9 offer a standard and novel approach, respectively, to develop military MoEs. Chapter 8, entitled "Multiple-objective decision-making," focuses on practical, conventional methods used to structure a military CBA when faced with the challenge of quantifying non-monetary benefits of defense projects, programs, or policies. Professors K. Wall and C. MacKenzie confront the challenge of non-monetary benefits leveraging the literature on multiple-objective (and multi-criteria) decision-making. The authors present a standard approach to help solve multiple-objective decision problems. Many contemporary decision problems in defense management and government resource allocation produce multiple, competing benefits. This chapter offers the widely employed analysis of alternatives (AoA) approach.

Chapter 9 offers a new, cutting-edge approach to conduct a military CBA focused on force protection investments. If the goal is to evaluate investments to protect soldiers, then monetizing the benefits of lives saved can help save the

greatest number of lives. In this chapter, entitled "A new approach to evaluate safety and force protection investments: the value of a statistical life," Professors T. Kniesner, J. Leeth, and R. Sullivan cogently discuss how economists evaluate the benefits of safety investments by observing tradeoffs people actually make between safety and other job or product characteristics. The authors present a widely relevant application of their technique to evaluate the cost-effectiveness of adding armor protection to tactical wheeled vehicles. The value-of-statistical-life (VSL) approach presented in this chapter is an innovative military CBA technique highly recommended for future safety and force protection investments.

1.3.4 Part IV: New approaches to military cost–benefit analysis

In Chapter 10, entitled "The role of cost-effectiveness analysis in allocating defense resources," Professor K. Wall joins forces with C.J. LaCivita and Professor A. Richter (a co-editor) to present a new CBA approach to solve multi-level (multi-tiered) resource allocation problems. Their solution method re-interprets the conventional AoA model with a twist. Applying standard operations research techniques, they incorporate bounded rationality to realistically portray how decision-makers can and do cope with the complexities of multi-level constrained optimization.[33] The bounded rationality formulation employs subjectively assessed weights derived from the judgment and expertise of a central allocator (e.g. the Minister of Defense), that offer guidance to lower-level decision-makers (e.g. the Services: Army, Navy, Air Force) to balance costs and MoEs in building defense proposals.

Another new, groundbreaking military CBA approach is introduced in Chapters 11 and 14. Chapter 11 is entitled "A risk-based approach to cost–benefit analysis: strategic real options, Monte Carlo simulation, knowledge value added, and portfolio optimization." In that chapter renowned expert J. Mun and Professor T. Housel present their pioneering "real options" approach that estimates military returns on investment (ROI), combining risk analysis concepts and portfolio optimization techniques. Two dramatic events unfolded in recent history that fundamentally transformed the contemporary security landscape—the collapse of the Soviet Union and the tragedy of 9/11. From a single well-defined "cold war" nuclear threat, countries now face a wide range of diffuse risks: anything from failed states, terrorism, and arms proliferation to human trafficking, piracy, and cyber-attacks. This historic shift in the national security environment prompted many countries to switch from "threat-based" planning to "capabilities-based" planning (see Fitzsimmons (2007)). With emerging threats harder to predict, strategic planners recommend diversification—building broad portfolios of flexible defense capabilities to counter a wide range of possible security concerns. Chapter 11 offers a new, unconventional approach to military CBA designed to help build "capability portfolios." The strategic intent of the United States and other militaries is to maintain a military edge over rivals. Bureaucratic inertia and political lobbying by established defense firms, however, often result in too heavy a focus on prior conflicts. Research and development (R&D) expenditures

represent a real options approach to future contingencies where some, but not all, research is expected to lead to the development of new systems. R&D payments are similar to premiums paid for financial options in that they grant the government the right—but not the obligation—to exploit, defer or abandon R&D investments. Periodic adjustments are made based on research results, new budget realities, and the evolving defense environment.[34] This innovative chapter introduces hands-on applications of Monte Carlo simulation, real options analysis, stochastic forecasting, portfolio optimization, and knowledge value added.

The real options approach attempts to make the best possible decisions under uncertainty and to identify, analyze, quantify, mitigate, and manage risks for military options. In Chapter 12, entitled "Extensions of the Greenfield-Persselin optimal fleet replacement model: application to the Canadian Forces CP-140A Arcturus Fleet," D. Maybury adapts other recent developments in financial modeling to construct a stochastic fleet replacement/overhaul model to predict the optimal timing of replacement. The chapter provides an interesting military application that features a popular maritime surveillance aircraft (the CP-140A Arcturus, a Canadianized version of the Lockheed P-3 Orion).

1.3.5 Part V: Selected applications

The last five chapters provide a selection of valuable applications and lessons learned that correspond to the methods and concepts discussed in the preceding chapters. Chapter 13, entitled "Embedding affordability assessments in military cost–benefit analysis analysis: defense modernization in Bulgaria," by V. Georgiev presents an application of the Economic Evaluation of Alternatives (EEoA) in Bulgaria's defense organization. The next two chapters each present real-world applications of military CBA, and are authored by subject matter experts with direct experience in high profile defense programs. Former program manager J. Dillard joins forces with Professors D. Angelis and D. Ford to review development of the Javelin anti-tank weapon system in Chapter 14 entitled "Real options in military acquisition: a retrospective case study of the Javelin anti-tank missile system." Study director W. Greer reviews the C-17 strategic airlift program in Chapter 15 entitled "An application of military cost–benefit analysis in a major defense acquisition: the C-17 Transport Aircraft." Whereas the former study provides a retrospective application of the "real options" approach, the latter offers a valuable historical perspective of traditional military CBA.

In Chapter 16, entitled "Cost-effectiveness analysis of autonomous aerial platforms and communications payloads," Commander (USN) R. Everly, Lieutenant (USN) D. Limmer and Professor C. MacKenzie build a traditional military CBA to evaluate investments in UAVs. The final chapter, by economists J. Hanson and J. Lipow, tackles a thorny issue: the so-called "social rate of discount." The debate among economists on whether, and by how much, to discount future costs in public procurement remains unresolved. Chapter 17, entitled "Time-discounting in military cost–benefit analysis" cogently summarizes the literature and contrasts it with current guidelines published by the US Office of Management and Budget