



Air Force Capability Development Planning

Analytical Methods to Support
Investment Decisions

James A. Leftwich, Debra Knopman, Jordan R. Fischbach,
Michael J. D. Vermeer, Kristin Van Abel, Nidhi Kalra

For more information on this publication, visit www.rand.org/t/RR2931

Library of Congress Cataloging-in-Publication Data is available for this publication.

ISBN: 978-1-9774-0308-7

Published by the RAND Corporation, Santa Monica, Calif.

© Copyright 2019 RAND Corporation

RAND® is a registered trademark.

Limited Print and Electronic Distribution Rights

This document and trademark(s) contained herein are protected by law. This representation of RAND intellectual property is provided for noncommercial use only. Unauthorized posting of this publication online is prohibited. Permission is given to duplicate this document for personal use only, as long as it is unaltered and complete. Permission is required from RAND to reproduce, or reuse in another form, any of its research documents for commercial use. For information on reprint and linking permissions, please visit www.rand.org/pubs/permissions.

The RAND Corporation is a research organization that develops solutions to public policy challenges to help make communities throughout the world safer and more secure, healthier and more prosperous. RAND is nonprofit, nonpartisan, and committed to the public interest.

RAND's publications do not necessarily reflect the opinions of its research clients and sponsors.

Support RAND

Make a tax-deductible charitable contribution at
www.rand.org/giving/contribute

www.rand.org

Preface

The Air Force Research Laboratory (AFRL) Strategic Development Planning and Experimentation (SDPE) Technology Directorate was established in 2016 to provide analytical support to the Air Force's corporate capability development efforts. SDPE was launched along with the Capability Development Council (CDC) and the Capability Development Working Group (CDWG) in part as a response to a 2014 report of a committee of the National Academies' Air Force Study Board recommending that the Air Force reinvigorate its approach to enterprise-wide capability development planning (CDP). In the spring of 2017, RAND Project AIR FORCE (PAF) was asked to review the processes and methods being used by SDPE and to identify other analytical methods that SDPE could employ to inform capability development and long-term investment trade-off decisions across core functions and multiple domains. After the initiation of this project, the Secretary of the Air Force (SECAF) and the Chief of Staff of the Air Force (CSAF) established the Air Force Warfighting Integration Capability (AFWIC), the purpose of which was in part to incorporate the capability development function, including the CDC and CDWG, within its larger mission of future force design. SDPE's role in AFWIC has not as yet been fully resolved, although the questions SDPE asked PAF to address remain no less relevant now than they were in early 2017.

This report retains its focus on analytical approaches in support of CDP, but decidedly not on the larger questions of defense planning. First, it reviews the processes and approaches to CDP that the Air Force currently uses. It next presents a "choice of methods" framework that SDPE could employ to support AFWIC's decisions about how much to invest in current and prospective capabilities in the presence of uncertainties and varying degrees of complexity in simulating future conditions and capabilities. Finally, the report describes the application of an initial "decision-framing" step applicable to virtually all methods of decisionmaking under uncertainty to an element of the Air Force's investment choices problem.

The audience for this report includes SDPE leadership; AFWIC's leadership and other senior Air Force leaders involved in the Air Force strategy, planning, and programming process (SP3); and analysts supporting CDP within the Air Force. Development planners within the other military services might also find the material on the "choice of methods" helpful in support of their own capability planning activities.

The research reported here was commissioned by the Air Force Strategic Development Planning and Experimentation Office and conducted within the Resource Management Program of RAND Project AIR FORCE as part of a fiscal year FY17 project Evaluation of the Strategic Development Planning and Experimentation Technology Directorate's Analytical Framework.

RAND Project AIR FORCE

RAND Project AIR FORCE (PAF), a division of the RAND Corporation, is the U.S. Air Force's federally funded research and development center for studies and analyses. PAF provides the Air Force with independent analyses of policy alternatives affecting the development, employment, combat readiness, and support of current and future air, space, and cyber forces. Research is conducted in four programs: Force Modernization and Employment; Manpower, Personnel, and Training; Resource Management; and Strategy and Doctrine. The research reported here was prepared under contract FA7014-16-D-1000.

Additional information about PAF is available on our website: <http://www.rand.org/paf/>

This report documents work originally shared with the U.S. Air Force on May 23, 2018. The draft report, issued on May 15, 2018, was reviewed by formal peer reviewers and U.S. Air Force subject-matter experts.

Contents

Preface.....	iii
Figures.....	vi
Tables.....	vii
Summary.....	viii
Acknowledgments.....	xix
Abbreviations.....	xx
1. Introduction.....	1
Background and Purpose.....	1
Definition of Development Planning.....	2
Brief History of Capability Development Planning in the Air Force.....	4
Prior RAND Research Related to Development Planning.....	6
In This Report.....	7
2. Capability Development Planning in the Air Force.....	8
Strategy, Planning, and Programming Process.....	8
Strategy, Planning, and Programming Process and Capability Development Planning.....	9
Air Force Activities to Support Capability Development Planning.....	11
Strategic Development Planning and Experimentation.....	13
Summary and Findings on Strategic Development Planning and Experimentation Activities and Analytical Needs.....	18
3. Current Assessment and Aspirational View of Capability Development Planning.....	21
Assessment of Recent Capability Development Planning Efforts by the Air Force.....	21
An Aspirational View of Capability Development Planning.....	24
Analysis to Inform Capability Development Planning.....	27
4. Analytic Methods for Capability Development Planning.....	28
Attributes of the Investment Problem.....	28
An Approach to Framing the Investment Choice Problem.....	32
Analytical Methods Applicable to Capability Development Planning.....	36
Implications for the Air Force of Adopting Decisionmaking Under Deep Uncertainty Methods.....	44
Steps Toward an Air Force Capability Development Planning Application.....	49
5. Decision-Framing Exercise.....	50
Workshop Process.....	50
Summary of Results.....	50
Key Findings and Conclusions.....	57
6. Recommendations and Next Steps.....	59
Appendix: Background Information on Capability Development Planning and Strategy, Planning, and Programming Process.....	62
References.....	64

Figures

Figure S.1. Choice of Methods Framework.....	x
Figure S.2. Basic Steps of Robust Decisionmaking	xii
Figure S.3. Steps in Assumption-Based Planning	xiii
Figure 2.1. Strategy, Planning, and Programming Process and Capability Development Planning	10
Figure 2.2. High-Level View of Strategic Development Planning and Experimentation Activities	14
Figure 2.3. Air Force Experimentation Process Flowchart.....	17
Figure 3.1. Developing the Future Force Structure in a Dynamic Capability Development Environment.....	25
Figure 4.1. Strategic Development Planning and Experimentation Activities Characterized by Level of Uncertainty and Complexity.....	31
Figure 4.2. Pyramid of Models	36
Figure 4.3. Steps in Assumption-Based Planning.....	40
Figure 4.4. Structure of Uncertainty-Sensitive Planning.....	41
Figure 4.5. Iterative Process of Robust Decisionmaking.....	42
Figure 4.6. Choice of Methods Framework	45
Figure 5.1. A Notional Integrated Modeling Approach for a Capability Development Planning Problem.....	56
Figure A.1. Capability Development Planning Logic Model	62

Tables

Table S.1. Uncertainties, Relationships, Strategic Levers, and Outcome Metrics	
Framework for Capability Development Planning	xiv
Table 4.1. Uncertainties, Relationships, Strategic Levers, and Outcome Metrics	
Framework for Air Force Capability Development Planning Problem-Framing	32
Table 5.1. Notional Uncertainties, Relationships, Strategic Levers, and Outcome Metrics	
Framework for Capability Development Planning	51

Summary

When the Air Force renewed its focus on capability development planning (CDP) in 2016, it established an internal governance structure to help transcend the constraints of CDP and budgeting. In October 2017, the Chief of Staff of the Air Force (CSAF) and the Secretary of the Air Force (SECAF) took the further step of creating the Air Force Warfighting Integration Capability (AFWIC), whose responsibilities would encompass not only CDP but concept development and future force design. Prior to the establishment of AFWIC, RAND Project AIR FORCE (PAF) was asked to (1) review the processes and methods being used by the new CDP governance structure; (2) identify analytical methods to inform long-term investment trade-off decisions across functional areas and multiple domains; and (3) demonstrate the application of an appropriate analytical method to CDP. Over the course of the project, as AFWIC's activities came into better focus, RAND PAF updated its representation of CDP and related planning processes.

Review of Current Capability Development Planning Processes and Methods

The PAF team reviewed capability development processes used by the new governance structure put in place in 2016. The review, conducted prior to the creation of AFWIC, included discussions with CDP stakeholders and examination of documents generated under several ongoing capability development initiatives. The team made several observations as a result of the review:

- Current processes and decisions are not systematically accounting for uncertainties or vulnerabilities in areas such as technology advances and failures, acquisition, budget, and future threats in the evolving global security environment.
- Planning and programming environments are not well aligned, and, consequently, near-term budgets do not necessarily support the implementation of capability development decisions.
- Decisions regarding capability gaps, priorities, and program divestments are not necessarily supported by analysis of impacts on resource allocation and future force needs.

CDP relies on hypothesis testing through experimentation and data gathering to better understand processes, technology readiness, and systems performance. The Air Force currently utilizes suitable analytical approaches to address this important but generally well-constrained type of problem. Unfortunately, the demands of CDP are broader than the progression of steps in technology development. Senior Air Force leaders must also make higher-level choices and set

priorities among alternative investment options under a wide range of uncertain futures, and do so in a timely manner. This type of problem presents larger analytical challenges to the Air Force because

- uncertainties about the future threat environment, rate of technological advancement, and budgeting cannot be characterized with probabilities, and
- making investment trades across warfighting domains and functional areas and representing effects of weapon systems and their interactions are complex and extremely challenging problems to simulate.

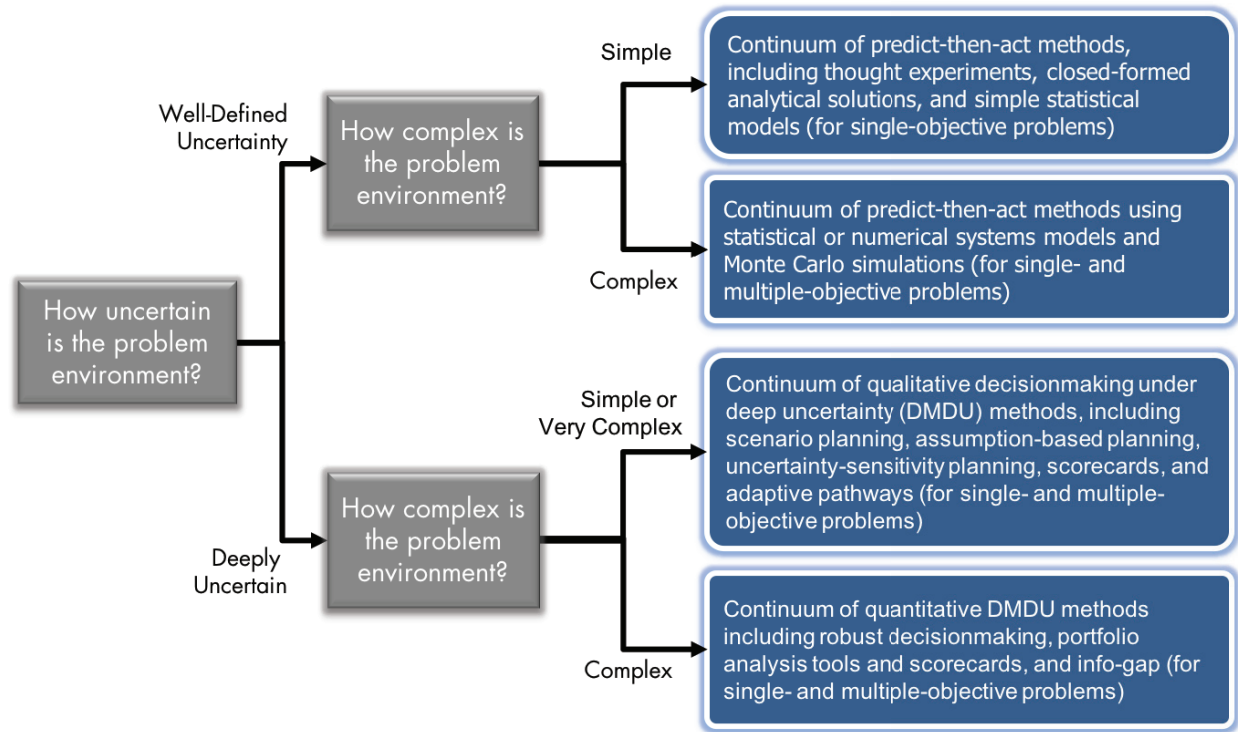
Analytical Methods to Support Capability Development Planning

To inform the Air Force’s analytical methods selection for CDP, RAND PAF developed a “choice of methods” framework, shown in Figure S.1, to highlight different analytical approaches the Air Force could employ to inform decisions, given varying uncertainties, complexities, and objectives. Distinguishing *well-defined uncertainty* from *deep uncertainty* is itself a serious analytical task. By *well-defined uncertainty*, we mean that the realization of a particular outcome (or more generally, a random variable) can be described by an empirical or theoretical probability distribution and that this distribution is knowable through observation. In contrast, outcomes of some phenomena that cannot be described by a probability distribution represent deep uncertainty. As a general matter, the complexity of a decision problem can be defined by the number of decisionmaking objectives; the number of options to choose from; and the number of interdependent, nonlinear, and other relationships among and between options and outcomes.

A number of approaches to decisionmaking under uncertainty have been developed over the years for many different types of decision problems. Differences among these approaches are characterized by the nature of uncertainties (in the system of interest as well as the external environment), levels of complexity in relationships between inputs and outputs to the system, and the number of objectives that solutions are intended to meet. Some methods use scorecards to choose among alternatives when multiple objectives are in play. Others approach the decision as a portfolio selection or resource (funding) allocation problem. In virtually all methods, costs are limited. However, standard economic valuation methods such as benefit-cost analysis or cost-effectiveness analysis are rarely if ever appropriate for national security problems.

For problems in which uncertainty can be well characterized and a single performance objective (e.g., minimize attrition) can be identified, it is reasonable to structure a problem-solving approach in terms of optimization: what choices yield the best outcome subject to a budget constraint. However, when problems have more than one objective, as is typical in the realm of national defense, simple optimization no longer holds, and a multiple-objective problem structure is required, implying trade-offs across objectives and therefore no single “right” answer. Decisionmakers then typically seek a solution that will do reasonably well across all objectives.

Figure S.1. Choice of Methods Framework



In this study, we focus on the deep uncertainty branch of Figure S.1: decision analysis methods that appear best suited for the kinds of deep uncertainty about the threat environment and trajectories of technological development faced by the Air Force in its CDP. For these problems, optimization is no longer an option, even for a single-objective problem. Solutions may vary depending on the assumed scenario (i.e., the particular combination of uncertain factors that bounds future conditions), but choosing a solution that does well only under one scenario and poorly under others would not be a prudent course of action. A better approach to decisionmaking is to choose solutions that are flexible, adaptable, and robust (FAR). These types of solutions are more desirable because they allow for the inevitable change in conditions, whether in the threat or the rate of technology development, and enable learning and adjustments along the way. CDP should structure around FAR-type problem statements.

Methods to handle problems characterized by both deep uncertainty and complexity differ primarily in their decision rules and assumptions about the nature of uncertainties. Virtually all of these methods take a systems view of capabilities to meet some desired effects or endpoints. For example, Robust Decisionmaking (RDM) uses various measures of robustness that favor adaptive or other types of strategies or actions that will perform well across many possible futures, without prejudice within the analysis itself as to the likelihood of these futures. Another nonprobabilistic approach with a robustness decision criterion is called “Info-Gap.” Like RDM, Info-Gap does not provide decisionmakers with a single solution; rather, it seeks to inform them

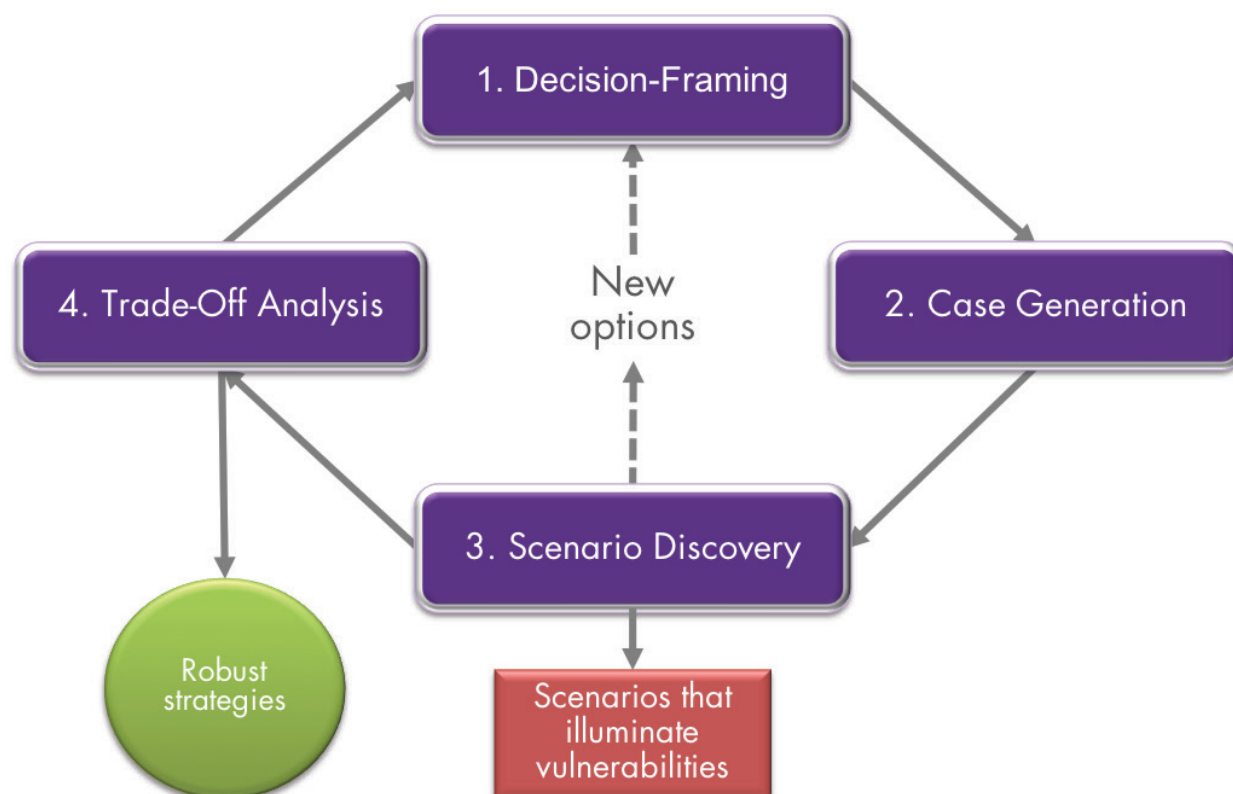
about vulnerabilities, risks, and trade-offs. In contrast to RDM, Info-Gap requires planners or decisionmakers to make an *a priori* judgment about the worst-case scenario that could be tolerated.

As a particular illustration of decisionmaking under deep uncertainty (DMDU) methods, we focus on RDM and consider its relevance to the Air Force's task, now residing within AFWIC, of identifying robust and adaptive capability development investment pathways to guide modernization efforts and the design of the future force. RDM rests on a simple concept. Rather than using models and data to assess policies under a single set of assumptions, in RDM, models are run over hundreds to thousands of different sets of assumptions about the problem space with the aim of understanding how plans perform under many plausible conditions.

As shown in Figure S.2, the basic steps of RDM, each of which feeds the next, include:

- Step 1—Decision-Framing: Decisionmakers and stakeholders identify important metrics that reflect their goals, management strategies, and policies (levers) considered to pursue goals; uncertain factors that may affect ability to reach goals; and the relationships among metrics, levers, and uncertainties, typically captured within one or more simulation models.
- Step 2—Case Generation: This step can be done qualitatively or quantitatively, depending on the feasibility of using one or several integrated mathematical models that can simulate the full range of effects from existing and potential capabilities and force structures against a wide range of plausible future conditions. In a quantitative approach, a model would be run many times under different combinations of future conditions to generate what are called *cases*. At this point in time, high-resolution models suitable for CDP do not exist. Therefore, a more qualitative approach or one informed by low-resolution models could be used.
- Step 3—Vulnerability Assessment and Scenario Discovery: Scenarios are descriptions of possible futures across a range of uncertain conditions. In a quantitative approach, decision-relevant scenarios can be identified mathematically in a scenario space where vulnerabilities are highest, which, in turn, enables identification and analysis of strategies or investments that might be most effective at mitigating or neutralizing the effects of these challenging conditions. This step then provides the essential inputs for a trade-off analysis where the performance of alternative investments, as identified by Air Force stakeholders, can be simulated quantitatively or worked through in qualitative terms to assess their effectiveness in reducing vulnerabilities.
- Step 4—Trade-Off Analysis: Using robustness as the decision criterion, decisionmakers attempt to converge on an investment strategy that will perform well over the scenarios of interest. The aim is to identify a portfolio of future force design decisions and capabilities that are flexible, adaptive, and robust as opportunities, threats, capabilities, and uncertainties change over time.

Figure S.2. Basic Steps of Robust Decisionmaking

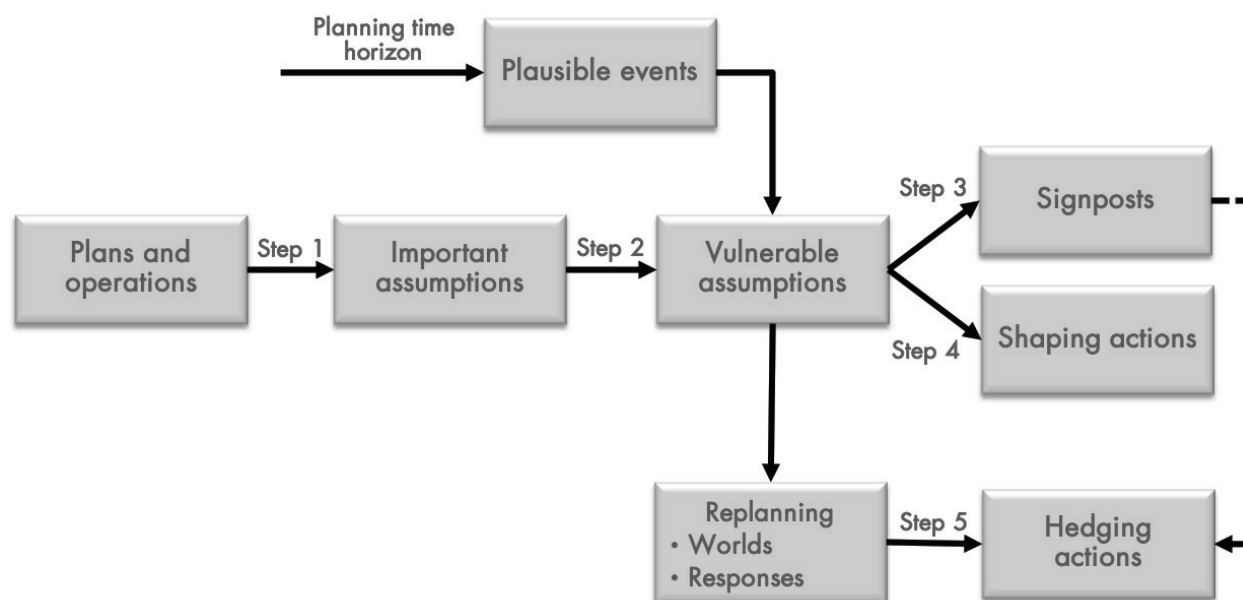


Whether applied in a qualitative or quantitative mode, this approach to decision-framing and uncertainty could be useful throughout the Air Force’s strategy, planning, and programming process (SP3).

A well-tested and pragmatic qualitative alternative to RDM is Assumption-Based Planning (ABP). As shown in Figure S.3, ABP hinges on identifying *load-bearing assumptions* (assumptions that, if broken, would require major revision of the course of action) and subsequently the vulnerability of those load-bearing assumptions. Once identified, ABP guides organizations in determining a course of action to deal with the vulnerability of load-bearing assumptions by developing

- **signposts**—explicit signals that may provide early warning of the vulnerability of load-bearing assumptions
- **shaping actions**—actions that attempt to control the vulnerability of load-bearing assumptions
- **hedging actions**—actions that attempt to better prepare the organization for the potential failure of a load-bearing assumption.

Figure S.3. Steps in Assumption-Based Planning



SOURCE: Dewar et al., 1993, Figure 7.1.

Compared to existing methods currently in use for CDP, either the ABP or RDM paradigm could support investment decisionmaking in situations when evidence is lacking to quantify the probability of future threats and risks, and in the face of the *deep uncertainties* (defined as phenomena in which probability distributions are unknown or unknowable).

Notional Demonstration of Decision-Framing Applied to Capability Development Planning

Having identified both RDM and ABP as appropriate problem-framing methods for CDP's analytical challenges, the team sought a means to demonstrate their potential value and challenges. Because a full demonstration was beyond the resources, timing, and scope of the project, the team focused on decision-framing, the first step in RDM, ABP, or indeed just about any decisionmaking under a deep uncertainty approach. This step was completed using the uncertainties, relationships, strategic levers, and outcome metrics (XLRM) framework as a simple means of organizing a focused discussion of how a CPD decision could be framed.

Table S.1 provides an overview of an XLRM workshop undertaken with RAND analysts knowledgeable about the Air Force, decision support analytics, and military strategy.

Table S.1. Uncertainties, Relationships, Strategic Levers, and Outcome Metrics Framework for Capability Development Planning

Uncertainties (X)	Levers, Options, Strategies (L)
Security environment (e.g., nature of conflict, partnerships, adversary intent)	Force structure choices
Domestic and foreign policy (e.g., political risk tolerance)	Investment
DoD strategy	Divestment
Attribution/targeting	Modernization strategy
Baseline support for and from other services	Enhance existing capabilities
Institutional abilities/biases to execute strategy	Acquire new capabilities
USAF operations	Extent and tempo of experimentation
Operational strategy with constraints	Acquisition strategy/approach
Basing strategy	
Readiness level	
Acquisition performance	
Availability of deployable technologies	
USAF budget	
Relationships/Models (R)	Outcome Metrics (M)
Campaign models	Cost
STORM	LCCs of buying and owning force structure
SUPPRESSOR	Collateral mission effect/kill-chain costs
THUNDER	beyond LCCs of <i>using</i> force structure
Combat effects models	Operational success
AFSIM platform	Time to win
BRAWLER	Rate of attrition
Cost-estimation models	Damage to adversary (conditional on adversary and situation)
Life-cycle costs (LCCs)	Collateral damage
Mission effects/kill-chain costs	Deterrence (absence of conflict)

Uncertainties

There are different types of uncertainties associated with CDP and long-term investment decisions. Some uncertainties can be considered outside the control of the Air Force. Those exogenous uncertainties are listed in Table S.1 and span the future security environment, acquisition performance, federal budgets, rates of maturation of technologies, and innovation cycles. If a quantitative RDM analysis for capability development were feasible, varying levels of each of these uncertainties would be represented within a simulation model (e.g., as a model parameter or constraint) and used to construct a wide range of possible cases over which the vulnerability of future force structures would be estimated. Otherwise, these uncertainties would be represented in a qualitative analysis by defining the bounds of “scenario space.” Other types of uncertainties are associated with simulation modeling tools, such as errors inherent in the model’s structure and uncertainties in the estimates of parameters embedded in the model. Still other uncertainties can be found in the efficacy and effectiveness of the levers, options, and

strategies (L) in Table S.1. Finally, outcome metrics also carry uncertainties related to the analytical challenges of quantifying them and their durability over the time period being analyzed.

Relationships

Ideally, RDM analysis of CDP would use a well-integrated hierarchy of validated campaign, mission, and engagement models. Campaign-level models would be used to analyze how different future force structures perform in varying future security environments. Mission and engagement models would be used to analyze performance of newly emergent technologies, concepts of operations (CONOPs), or modifications of existing platforms or munitions. Additionally, in an RDM application, cost models would be used to estimate the cost of owning the force structure and the cost of using the force structure to deliver the combat effects required to defeat adversaries across a range of plausible futures.

At the present time, this type of complex integrated or hierarchical modeling platform does not exist. Hence, the Air Force will need to continue to work with simpler modeling approaches to explore effects that can be achieved under different future force designs and CONOPs, recognizing explicitly the assumptions built into these reduced-form representations of reality. Taking a long view of model development, the Air Force could over time deliberately build toward a more robust set of modeling tools suitable for CDP, but it is clear from experience thus far that models built for more limited purposes may not be capable of delivering the insights needed at the more strategic level of CDP.

Strategy Levers

The levers in CDP are force structure choices, as well as strategies for modernization, acquisition, basing, and operations employed by the Air Force to meet current or future warfighting needs. The primary class of levers, and the one at the heart of capability development, is the weapon systems platforms and associated enablers.¹ In a quantitative RDM analysis, some type of mathematical model, as discussed in the “Relationships” section above, is needed to assess the relative cost and effectiveness of portfolios of levers across a range of possible futures. In a qualitative analysis, these relationships could be developed through a combination of review of technical literature and expert elicitation. Each combination of levers (a set of levers is called a *portfolio*) and a particular future (a unique combination of uncertainties, as described above) is called a *case*. Results from all cases would be stored in a database that could then be queried by decisionmakers through visualization software to gain

¹ AFWIC is charged with documenting the future force structure in a product called the *Design Blueprint*. This is to be AFWIC’s most significant output.

insights into cost and effectiveness trade-offs across the portfolios and the robustness of portfolios across the range of possible futures. A budget constraint could be imposed at different levels and the effectiveness of portfolios of weapon systems and their enablers estimated at the force structure level, deferring for later in the planning and programming process more detailed cost estimation required for appropriations-level decisions.

Outcome Metrics

This is arguably the most important step in the decision-framing process because it sets the terms of engagement between the values and preferences of decisionmakers and the effects they seek to achieve with a future force structure. For example, workshop participants identified three key outcomes measures for the CDP analysis: operational success, deterrence, and cost. Each of these measures would need to be further decomposed into measurable terms. Thus, operational success could relate to attrition of both red and blue forces (by type), by duration of campaign, or by durability of supply lines. These measures would need to be evaluated across the scenario space or for a well-chosen spanning set of test scenarios.

Findings

Implementation of any type of DMDU approach poses a set of challenges to the Air Force. The XLRM exercise revealed the layers of complexity embedded within the CDP challenge to produce decision-quality analysis to support design and planning choices. CDP is a difficult problem (as is force structure design). The most difficult step comes at the beginning, when the decision problem itself is being framed. Is the right question being asked? Is it analytically tractable? Do the levels of uncertainty and complexity justify the use of the analytical method chosen? While the performance measures may appear relatively straightforward, data to inform those measures may not be accessible. Similarly, coupling models or data sets to accurately capture the effect of adjusting levers will be highly dependent on the availability of models and their fidelity. Workshop participants noted that while models at the appropriate level of abstraction may be difficult to come by, these types of models are worthy of development in support of CDP.

These types of technical limitations are one class of implementation challenges. Another type of implementation challenge relates to the practicalities of developing competencies in a new approach for which the capabilities may need to be built rather than simply adapted. This capability may need to be resident in AFWIC as well as Strategic Development Planning and Experimentation (SDPE) and AF/A9. A question for SDPE going forward relates to the adequacy of internal staffing and capacity to support CDP. Projections of SDPE's future staffing were unresolved at the time of this study.

Finally, the introduction of a new approach to analysis—and really, a new way of thinking—can be difficult within any organization. RDM and similar methods represent a fundamental shift in problem-solving from prediction-then-act analysis and decisionmaking to the RDM alternative

of a risk management approach of seeking robust solutions across a range of future threat environments and other uncertainties. The key output of this type of approach is not a single answer but rather trade-off curves or other visualizations that compare performance of alternative strategies or portfolios of options to the status quo or other baseline in terms of metrics that reflect what is most important to the Air Force.

Next Steps and Conclusions

As a first step, we recommend that SDPE, in consultation with AFWIC, choose a timely and relevant investment decision problem. Given the absence of appropriate modeling tools for CDP, we recommend that SDPE demonstrate the robustness of a number of alternative investment portfolios using a mostly qualitative approach such as ABP that would alleviate the need for sophisticated—or nonexistent—models capable of encompassing a range of emerging technologies, such as quantum computing, artificial intelligence, hypersonics, or directed energy. The analysis would consider performance under a wide range of future conditions and visualize trade-offs among these alternatives across the performance metrics relevant to Air Force decisionmakers. For example, a tractable piece of one of the following illustrative problems could be chosen that would draw on an existing and well-understood functional or mission-level model:

- succeeding in combat against increasingly capable integrated air defense systems (IADS)
- providing robust close air support (CAS)
- maintaining robust capabilities to conduct long-range strike
- integrating communications, surveillance, reconnaissance, and targeting (CSRT) across the Air Force and Joint Force.

To be workable, a test application will need to be amenable to analysis. There are several desirable criteria.

- Models should be understandable and appropriate for exploring broad-ranging uncertainty analysis, meaning that they are relatively simple and parsimonious with respect to variables and parameters; in the absence of numerical models, conceptual models may be used.
- There should be basic access to data that could be used to establish performance under a baseline or status-quo CONOPs and existing capabilities.
- Classification levels should be managed to enable serious analysis and reveal key developments underway but not overly restrict the necessary audience of key analysts and decisionmakers.
- AFWIC, SDPE, major command (MAJCOM), and Joint Force stakeholders should be willing to engage in an iterative process in developing the XLRM matrix, including the

identification of performance metrics, key uncertainties, modeling tools, and investment/divestment strategies (levers).

- The problem can be scoped to accommodate a qualitative analysis within 8–12 months of initiation, including all relevant data collection, modeling, analysis, visualization, and interactive review of and response to results.

Two additional criteria cannot be met at this time.

- There would have to be one or more existing simulation models that with only modest adjustments could capture effects on campaigns of the scale of the threat, CONOPs, and technology alternatives under consideration. While campaign models may in theory be good for integration, they are not suitable for assessing the efficacy of cyber-based methods, new technologies reliant on artificial intelligence, or a particular defensive strategy such as IADS.
- The simulation models would need to be fully accessible to analysts for easy configuration for batch processing.

SDPE is well positioned to lead in developing some of these modeling capabilities. Cultivating a close, collaborative, trust-based relationship with the AFWIC team will be essential to SDPE's effectiveness as a leader in decision support to the Air Force development planning enterprise. Thus, AFWIC's engagement will be needed at each step of the application process.

Acknowledgments

Numerous people both within and outside the Air Force provided valuable assistance and support for our work. We thank Mr. Jack Blackhurst, Executive Director, Air Force Research Laboratory, for sponsoring this work. We also are indebted to the SDPE staff, especially Mr. Tom Lockhart, Mr. Chris Ristich, Maj Cassie Hidalgo, Mr. Rich Henke, Mr. Rudy Klosterman, Lt Col. Matthew (JD) Robbins, Mr. Chris Leak, Ms. Jessica Sawyers, and Mr. David Panson.

Many senior leaders in the Air Force made themselves available for interviews and discussions. We are particularly grateful for the wisdom and insights from the following individuals (listed alphabetically and identified by with their rank/grade and organizational affiliation at the time we met with them): Dr. Brian Beal, Principal Investigator, Data-to-Decision Experimentation Campaign; Lt Gen Arnold Bunch SAF/AQ; Mr. David (Doc) Ellis, AF/A5R; Mr. Brian Foley, ACC/A5/8/9; Col Tyler Gabriel, AF/A5R; Maj Gen Peter Gersten, AF/A8X; Lt Gen Jerry Harris AF/A5/8; Mr. Steve Hart, AF/A8X; Gen Mike Holmes, ACC/CC; Col Mike Koscheski, AF/A8X; Mr. Jerry Lautenschlagen, AF/AQR; Maj Gen John McMullen, ACC/CV; Maj Gen Russell Mack, ACC/A5/8/9; Mr. Jim Pitstick, AFMC/A9A; Brig Gen Chance Saltzman, MDC2 Lead; Mr. Jeff Stanley, SAF/AQR; Lt Gen Bradford Schwedo, SAF/CIO; and Maj Gen James Vechery, AF/A5R.

We also benefited from the expertise of Dr. Paul Kaminski and Mr. Blaise Durante. Finally, we are indebted to RAND colleagues who lent valuable insights to our efforts along the way: Brien Alkire, Irv Blickstein, Natalie Crawford, Michael Kennedy, Robert Lempert, Drew Lohn, Michael Mazurr, Steven Popper, and Obaid Younossi. Katherine Lee provided much-needed support in the conduct of our internal workshop. Finally, we thank Paul Davis and James Bonomo for their thorough and critical review of our draft manuscript. As always, we as authors are responsible for the final content of the report.

Abbreviations

ABP	Assumption-Based Planning
ACC	Air Combat Command
AFFOC	Air Force Future Operating Concept
AFGM	Air Force Guidance Memorandum
AFRL	Air Force Research Laboratory
AFSEA	Air Force Strategic Environment Assessment
AFSIM	Advanced Framework for Simulation, Integration, and Modeling
AFWIC	Air Force Warfighting Integration Capability
AS2030	Air Superiority 2030 ECCT
ATC	Applied Technology Council
C2	command and control
CAS	close air support
CCT	Capability Collaboration Team
CDC	Capability Development Council
CDP	Capability Development Planning
CDWG	Capability Development Working Group
COA	course of action
CONOP	concept of operations
CSAF	Chief of Staff of the Air Force
CSRT	communications, surveillance, reconnaissance, and targeting
DAPP	Dynamic Adaptive Pathways Planning
DMDU	decisionmaking under deep uncertainty
DoD	Department of Defense
DOTMLPF-P	doctrine, organization, training, material, leadership and education, personnel, facilities, and policy

DP	development planning
EC	experimental campaign
ECCT	Enterprise Capability Collaboration Team
FAR	flexible, adaptable, and robust
FY	fiscal year
HAF	Headquarters, Air Force
IADS	integrated air defense system
LCC	life-cycle cost
MAJCOM	Major command
MDC2	Multidomain Command and Control ECCT
NDS	National Defense Strategy
NRC	National Research Council
PAF	Project AIR FORCE
PNT	position, navigation, and timing
POM	Program Objective Memorandum
PPG	Plan-to-Program Guidance
R&D	research and development
RAP	Resource Allocation Plan
RDM	Robust Decisionmaking
S&T	science and technology
SECAF	Secretary of the Air Force
SDPE	Strategic Development Planning and Experimentation
SMP	Strategic Master Plan
SP3	strategy, planning, and programming process
STORM	Synthetic Theater Operations Research Model
USAF	U.S. Air Force
VCSAF	Vice Chief Secretary of Staff of the Air Force
XLRM	uncertainties, relationships, strategic levers, and outcome metrics

1. Introduction

Background and Purpose

To maintain air, space, and cyber superiority, the Air Force must continually update, improve, and transform its capabilities in response to ever-changing threats and new strategies and technologies employed by adversaries. In some cases, existing capabilities need only incremental adjustments to meet new challenges. In many others, however, the Air Force needs more ambitious transformations, not only in technology and hardware but also in nonmateriel areas and warfighting strategies. Such transformations require (1) clarity and specificity in strategic guidance; (2) a willingness of leadership to take risks in the presence of deep uncertainties about future threats; (3) access to the requisite expertise and analytical tools; and (4) predictability of funding. Transformation also requires research and development (R&D) investments and timely acquisition processes that are agile, adaptable, and robust to succeed in a rapidly changing world. *Development planning* is the name given to the set of analytical and decisionmaking processes the Air Force employs to anticipate, explore, and pursue R&D opportunities, acquisitions, and strategic adaptations that will enable it to fully support the National Defense Strategy (NDS) well into the future.

A committee of the 2014 National Research Council (NRC) Air Force Studies Board recommended that the Air Force reinvigorate its approach to enterprise-wide development planning (NRC, 2014). Partly in response to the NRC report, the Secretary of the Air Force (SECAF) and the Chief of Staff of the Air Force (CSAF) signed a charter in 2016 establishing a governance structure charged with guiding the Air Force's capability development effort and aligning it with the strategy, planning, and programming process (SP3) (James and Welsh, 2016). The governance structure consisted of the Capability Development Council (CDC), the Capability Development Working Group (CDWG), and the Strategic Development Planning and Experimentation (SDPE) Technology Directorate. SDPE's role was to provide analytical support to the Air Force's corporate capability development efforts (James and Welsh, 2016, p. 1).

In February 2017, SDPE asked RAND Project AIR FORCE (PAF) to assist in three tasks. First, the team was asked to assess the operations of SDPE and its processes and platforms for conducting analysis. Second, PAF was asked to evaluate analytical methods and processes that might apply to SDPE's activities. These activities are focused primarily on prioritizing capability needs and gaps that cut across the organizations of the Air Force, identifying options for filling those gaps, and recommending force structure investment and divestment options. For its third task, PAF was asked to support the SDPE by demonstrating one or more analytical methods applied to an anticipated cross-cutting capability planning activity or other high-priority, enterprise-wide task requiring decision-quality analysis.

In October 2017, the CSAF and the SECAF took a further step toward centralizing CDP by establishing the Air Force Warfighting Integration Capability (AFWIC) whose responsibilities would encompass not only CDP but concept development and future force design (USAF, 2017). AFWIC's concept of operations (CONOP) established a Capabilities Development Directorate (CDD), which

prioritizes, sequences, and directs integrated capability development activities (“means”) across known capability gaps as well as emerging opportunities. The CDD identifies, plans, and directs those activities that will develop capabilities from concepts into acquisition programs for the future force. These actions ensure an enterprise-wide, joint force–informed, holistic understanding of future capabilities (ways and means) linked to current capabilities that guide resource investment priorities. To effectively direct these activities, the CDD produces the Capabilities Development Guidance document, signed annually by the SecAF and CSAF. . . . This document provides strategic-level Air Force guidance and prioritization to the science and technology, experimentation, and development acquisition communities. This guidance manifests into a detailed and time-phased Capability Development Implementation Plan (CDIP), a 5-year plan signed by the AFWIC Commander. . . . The CDD, in coordination with SAF/AQR, functions as the secretariat for the VCSAF [Vice Chief of Staff of the Air Force]-chaired Capability Development Council providing more directive guidance and executive coordination of future force design decisions across the blueprint and ensuring alignment of capability development efforts in accordance with the future force design. (USAF, 2018, p. 5)

Over the course of the project, as AFWIC's activities came into better focus, the RAND PAF team updated its representation of CDP and related processes.

Definition of Development Planning

Development planning (DP) describes a systematic process of (1) identifying materiel and nonmateriel capabilities that provide the means to deliver warfighting effects consistent with Air Force strategic guidance; and (2) setting priorities for investments for success, as well as accounting for first-order estimates of costs and estimates of rates of maturation of emerging technologies. In its Communication Waypoints for Capability Development, the Air Force further describes DP and its key activities as follows:

- We are using DP and experimentation to understand and synthesize future warfighting needs and reconcile those with available and potential capabilities, concepts, and emerging technologies.
- Core DP functions: formulating and evaluating viable future concepts, defining operational trade space, identifying technology shortfalls and S&T

[science and technology] needs, and assisting the ops community in refining requirements. (USAF, 2016a)

Alternatively, the NRC Air Force Studies Board committee defined DP in terms of the question it needs to answer: “Over the next 20 years in 5-year increments, what capability gaps will the Air Force have that must be filled?” (NRC, 2014, p. 60). The NRC committee extended the definition of DP to include investments in the workforce: “Development planning will also provide for development of the workforce skills needed to think strategically and to effectively define and close the capability gap” (p. 60).

During our analysis, we found that these definitions did not fully capture the purpose of DP, the context in which it is performed, and what it informs.¹ For these reasons, we deliberately refer to DP in the broader context of its focus on producing capabilities needed by the future force to deliver combat effects. Accordingly, we use the term *capability development planning* (CDP), which we define as a careful and deliberative process of adaptive planning as the Air Force advances from its present set of capabilities to future sets as highly uncertain future circumstances demand.

At its core, CDP is a collection of analytical activities to support decisionmaking aimed at achieving a future force capable of supporting joint forces, engaging adversaries, and winning. CDP requires choices to be made about the planning time horizon (e.g., 10, 20, or 30 years); currently, the Air Force views its planning time horizon as 30 years. Further, CDP requires choices to be made about investment targets (whether they relate to kinetic or nonkinetic effects, materiel or nonmateriel means, grand strategies, or concepts of operations), divestment targets, and ultimately resource allocation. For example, the Air Force needs to decide when to seize technology opportunities and pursue high-risk, high-reward research. It further needs to decide when and how to adjust, refine, and redirect current weapon and enabling systems acquisitions to new ventures. And it must make all of these decisions within a budget constraint. CDP *should* consider uncertainties in all of these attributes of the planning environment, but under current Air Force practice, analysis of uncertainty is limited.

The primary output of analysis in support CDP is a multidimensional mapping of “tradespace,” meaning estimates of projected performance for various investment portfolios and a display of performance trade-offs across the Air Force’s multiple goals. Drawing on Davis

¹ Recognizing the fundamental uncertainties about how war might occur and details of how it might unfold, many analysts and military leaders pressed DoD to change its fundamental approach to planning. Ultimately, these discussions led Secretary of Defense Donald Rumsfeld to introduce the concept of capabilities-based planning in the 2001 Quadrennial Defense Review (QDR) (Rumsfeld, 2001, 2002). This shift was the result of many pressures over the previous decade by outside authors. See, for example, Davis (1994) and Davis, Kugler, and Hillestad (1997); outside panels such as the National Defense Panel that reviewed the 1996 QDR (National Defense Panel, 1997); as well as general officers, the Office of Net Assessment, and other analytical components of DoD.

(2014), we take the ultimate purpose of this approach to analysis to be to help leaders find strategies that are flexible, adaptive, and robust (FAR):

- flexible to accommodate changes in threats, missions, objectives, and constraints
- adaptive to changing circumstances including those of adversaries,
- robust to events, including both slow-moving trends and positive or negative shocks.

Leaders should expect no less than “FARness” in their plans.

This type of analysis should be accomplished using transparent methods that account for salient complexities, system and resource relationships and dependencies, and uncertainties. A mix of analytical tools may contribute to the quantification process, but many critical relationships within complex systems are by definition very difficult to quantify, and therefore, qualitative methods may be more feasible. Ultimately, the objective of CDP is an impartial characterization of tradespace as a means to facilitate investment decisions by Air Force leadership.

Brief History of Capability Development Planning in the Air Force

Developing capabilities for future forces has been and remains a complex undertaking within the Air Force, influenced by the uncertain development pathways of emerging technologies, budget constraints, and often competing interests among the internal Air Force communities representing research and development, acquisition, and the warfighter. Over its history, the Air Force has experienced periods of success and failure in attempting to navigate the complexities in a manner that delivers the needed capabilities at the required time. In reviewing the history of CDP, we draw primarily on information gathered for the NRC’s 2014 report on DP (NRC, 2014). Based on our review of DP history in the NRC report, we observe four periods of varying levels of effort, success, and failure. The *formative years* spanned a period from the creation of the Air Force up to 1977. The second period, which we term the *focused years*, started in 1978 and continued until the late 1990s. The *dormant years* started in the late 1990s and continued until about 2009. Finally, the *reemergent years* started in 2010 and continue to the present.

During the formative years, the Air Force experienced mixed success with DP. Not surprisingly for a new service, the Air Force tried various approaches to building future capabilities and saw its focus oscillate between developing new technologies and maintaining its current capabilities (NRC, 2014). The Advanced Systems Program Office emerged in 1960 and focused on DP, intent on forging tighter links between the research, acquisition, and operational user communities (NRC, 2014).

In the “focused years,” General Alton Slay, then the commander of Air Force Systems Command (AFSC), saw the need to institutionalize the execution of DP. General Slay instituted a methodology called “Vanguard.” There are several notable characteristics of the Vanguard process (NRC, 2014):

- tight integration between the warfighter, science and technology, and acquisition communities,
- a focus on different parts of the Air Force to include “mission planning, major force elements, and functional planning,”
- a heavy reliance on advanced computing tools, comprehensive and shared data, and robust analysis,
- frequent and structured interaction by Air Force senior leaders representing different warfighter and stakeholder communities.

Vanguard remained in place through General Slay’s tenure, but was replaced by Applied Technology Councils (ATCs) after he retired in 1981 (NRC, 2014). ATCs sought to carry on the integration between the three key DP stakeholder communities, and while they initially succeeded in carrying Vanguard’s momentum forward, they became less and less relevant in the DP world as a result of organizational changes in the Air Force during the 1980s and 1990s, which had the effect of further decentralizing planning.² The ultimate end of the focus years was in fiscal year (FY) 2000, when the Air Force’s DP budget was zeroed out by Congress (NRC, 2014). That action launched the dormant years, which continued until 2009.

DP reemerged as a focus in 2010, driven largely by the Weapon Systems Acquisition Reform Act of 2009 (WSARA). DP program lines were restored in the budget for FY 2010 and with it, efforts to better inform key milestone decisions as part of the acquisition process (NRC, 2014). The reemergence of interest in more centralized DP also prompted the 2014 NRC Air Force Studies Board report that led to the new governance structure and SDPE’s role.

Several elements of successful efforts can be drawn from this brief historical overview. First, successful DP periods were driven by senior leaders focused on identifying new capabilities and forging links among warfighter, science and technology, and acquisition communities. Carrying on General Henry “Hap” Arnold’s initial focus on DP when the Air Force first emerged as an independent service, General Bernard Schriever guided the DP efforts that led to the creation of the Air Force’s formidable missile capability (NRC, 2014). General Slay’s Vanguard process was instrumental in DP in the late 1970s. Absent his leadership, DP slowly atrophied in the years following his retirement in 1981 (NRC, 2014).

The second ingredient of successful and sustained DP efforts is a keen understanding of the role of analysis to inform DP decisions. In the early days, Generals Arnold and Schriever relied on a mix of Air Force analysts and leading analysts from industry and academia. Both

² The 2014 NRC report on development planning highlighted budget reductions, negative reports from the Government Accountability Office (GAO) on the Air Force’s development planning funding strategy, and the major Air Force reorganization that resulted in the merger of Air Force Logistics Command and Air Systems Command. This merger created the Air Force Material Command and Air Combat Command (from the Tactical and Strategic Air Commands) and likely contributed to the end of what we have termed the focus years.

recognized the limits of relying solely on Air Force personnel. Further, a key tenet of General Slay's Vanguard process was the required sharing of data and analysis across functional domains within the Air Force. This excerpt from the NRC report highlights the same need to focus on analysis as part of DP:

Tools available to the development planning community for cross-core function trade-offs and integrated force planning—with the capability to analyze, assess, simulate, and trade performance of the Air Force against a range of realistic and stressing scenarios utilizing a set of validated common models across the Air Force-wide portfolio—were not apparent. This analytical effort requires modern tools and knowledgeable analysts to perform the multivariate analysis needed to enable definition of the required force that meets Air Force needs, assures robustness, and maintains flexibility while operating in the fiscal constraints facing the nation and the Air Force today. The Air Force appears to lack these tools and the analyst cadre to use them. (NRC, 2014, p. 37)

Despite the importance of analysis to support DP, it has been and remains a challenge for the Air Force to establish and grow such a capability. SDPE was created in part to address this challenge.

Prior RAND Research Related to Development Planning

The topic of CDP and the analysis to support it has been the subject of RAND research for many years. The following is a selected listing of studies relevant to the subject of this report.

- *New Challenges in Defense Planning: Rethinking How Much Is Enough*, Paul K. Davis, MR-400-RC, 1994.
- *Issues and Options for the Quadrennial Defense Review*, Paul K. Davis, Richard Kugler, and Richard Hillestad, DB-201-OSD, 1997.
- *Resource Allocation for the New Defense Strategy: The Dynarank Decision Support System*, Richard Hillestad and Paul K. Davis, MR-1996-OSD, 1998.
- *Measuring Interdiction Capabilities in the Presence of Anti-Access Strategies: Exploratory Analysis to Inform Adaptive Strategies for the Persian Gulf*, Paul K. Davis, Paul K., Jimmie McEver, and Barry Wilson, MR-1471-AF, 2002.
- *Developing Resource-Informed Strategic Assessments and Recommendations*, Paul K. Davis, Stuart E. Johnson, Duncan Long, and David C. Gompert, MG-703-JS, 2008.
- *Portfolio-Analysis Methods for Assessing Capability Options*, Paul K. Davis, Russell D. Shaver, and Justin Beck, MG-662-OSD, 2008.
- *RAND's Portfolio Analysis Tool (PAT): Theory, Methods, and Reference Manual*, Paul K. Davis and Paul Dreyer, TR-756-OSD, 2009.

- *Lessons from RAND's Work on Planning Under Uncertainty for National Security*, Paul K. Davis, TR-1429-OSD, 2012.
- *Analysis to Inform Defense Planning Despite Austerity*, Paul K. Davis, RR-482-OSD, 2014.
- *Capabilities for Joint Analysis in the Department of Defense: Rethinking Support for Strategic Analysis*, Paul K. Davis, RR-1469-OSD, 2016.

We highlight this prior research for two reasons. The first is to provide some insight into different analytical methods that have been considered over the years as the Air Force and Department of Defense (DoD) have struggled with the particular challenges of conducting a technically credible CDP process. The second is to highlight and reinforce the complexity of the problem facing the Air Force's new CDP governance structure, and particularly SDPE, as it develops and evolves its analytical methods and associated analytical models to support CDP within AFWIC.

In This Report

This report synthesizes PAF's analysis and findings on CDP as currently practiced and as it might be done in the future, and it provides a framework for methods of analysis to support CDP. Chapter 2 sets the context by describing the current SP3, which feeds capability gaps and divestment options into CDP processes; current CDP and experimentation activities in the Air Force and how they fit into SP3 activities; and our assessment of current SDPE activities in support of Air Force DP and experimentation. Chapter 3 presents observations and shortcomings of current CDP and describes an aspirational approach that serves as the baseline requirement of our analytical methods framework. Chapter 4 describes methodologies and analytical methods for CDP and discusses their potential application to SDPE processes and activities. Chapter 5 reports on the results of an internal PAF workshop that implemented a "decision-framing" exercise, a first step for most decisionmaking under deep uncertainty (DMDU) problems to inform Design and Planning Choices events, the venues in which senior Air Force leadership make their CDP-related decisions. Finally, Chapter 6 summarizes findings and makes recommendations on actions SDPE could take going forward to enhance its support of CDP and experimentation activities, informed by judgments regarding implementation and technical capacity.

2. Capability Development Planning in the Air Force

This chapter provides an overview of SP3 and the relationship between the SP3 and CDP, as well as activities that support CDP. It also describes the planning activities of SDPE, including its charter, objectives, inputs, and activities. We assessed the current organizational structures, processes, and activities comprising Air Force CDP and experimentation and how current SDPE activities supported each element. Finally, the chapter describes the role of Air Force experimentation in developing capabilities and reducing uncertainties and concludes by discussing SDPE experimentation campaigns (ECs) in support of broader Air Force objectives. In light of ongoing changes, the chapter also considers SDPE's relationships with AFWIC, as currently understood, and other planning organizations and processes. Broader issues associated with defense planning are not addressed, as they are beyond the scope of this study.

The assessment of SDPE began with a review of recent literature and processes provided by SDPE staff, including the charters and other documents for SDPE, Enterprise Capability Collaboration Teams (ECCTs), ECs, and flight plans. PAF also reviewed literature on the Air Force SP3 and current DP and experimentation activities performed by SDPE. Using this information as a starting point, we created an interview protocol to guide our discussions of CDP and experimentation activities with senior leaders who serve as CDP decisionmakers, as well as with other staff who are stakeholders in the process. The literature review and notes from these informal discussions informed our assessment of current processes and activities described in this chapter.

Strategy, Planning, and Programming Process

We first sought to understand where SDPE's DP activities fit within the broader and recurring annual SP3. Air Force Guidance Memorandum (AFGM) 2016-90-1101, *Air Force Strategic Planning Process*, states: "The Air Force (AF) uses the Strategy, Planning, and Programming Process (SP3) to create Air Force forces able to provide responsive and effective Global Vigilance–Global Reach–Global Power to support the national strategy now and in the future environment." (USAF, 2016b, p. 1). It goes on to define the SP3 as a

process to integrate strategy, concepts, and capability development to identify force objectives and programming to support practical organization, training, equipping and posture across the Total Force. [It is] comprised of distinct, interrelated elements set in the context of Presidential and DoD guidance. The elements are categorized as Strategic Planning, Program Planning and Development, and Program Defense. (USAF, 2016b, p. 31)

The goal of the SP3 is to create the force structure the Air Force needs to accomplish its missions. It is intended to identify future challenges and manage concept development efforts to meet them. The process is described here briefly and in more detail in Appendix A.

The strategy element of the process is guided by the president's National Security Strategy (The White House, 2017) followed by DoD-level guidance and an assessment of future threats in the NDS (DoD, 2018). The NDS informs the Air Force Future Operating Concept (AFFOC), which describes how the Air Force intends to operate in the future. The Strategic Planning Guidance, a result of the strategy phase of the SP3, provides guidance to major commands (MAJCOMs) on the development of their core function plans. Their plans should be consistent with Air Force-level guidance and describe the type and quantity of force they need to perform their role/mission as part of the future force. MAJCOM plans take a near-term view of their capabilities but also attempt to project their long-term force and resource requirements. The SP3 ultimately leads to a statement of the midterm (ten-year) and long-term (30-year) future force structure and required capabilities.

Strategy, Planning, and Programming Process and Capability Development Planning

CDP has evolved within the Air Force in recent years (NRC, 2014). The Air Force 2015 Strategic Master Plan (SMP) says the following about capability development:

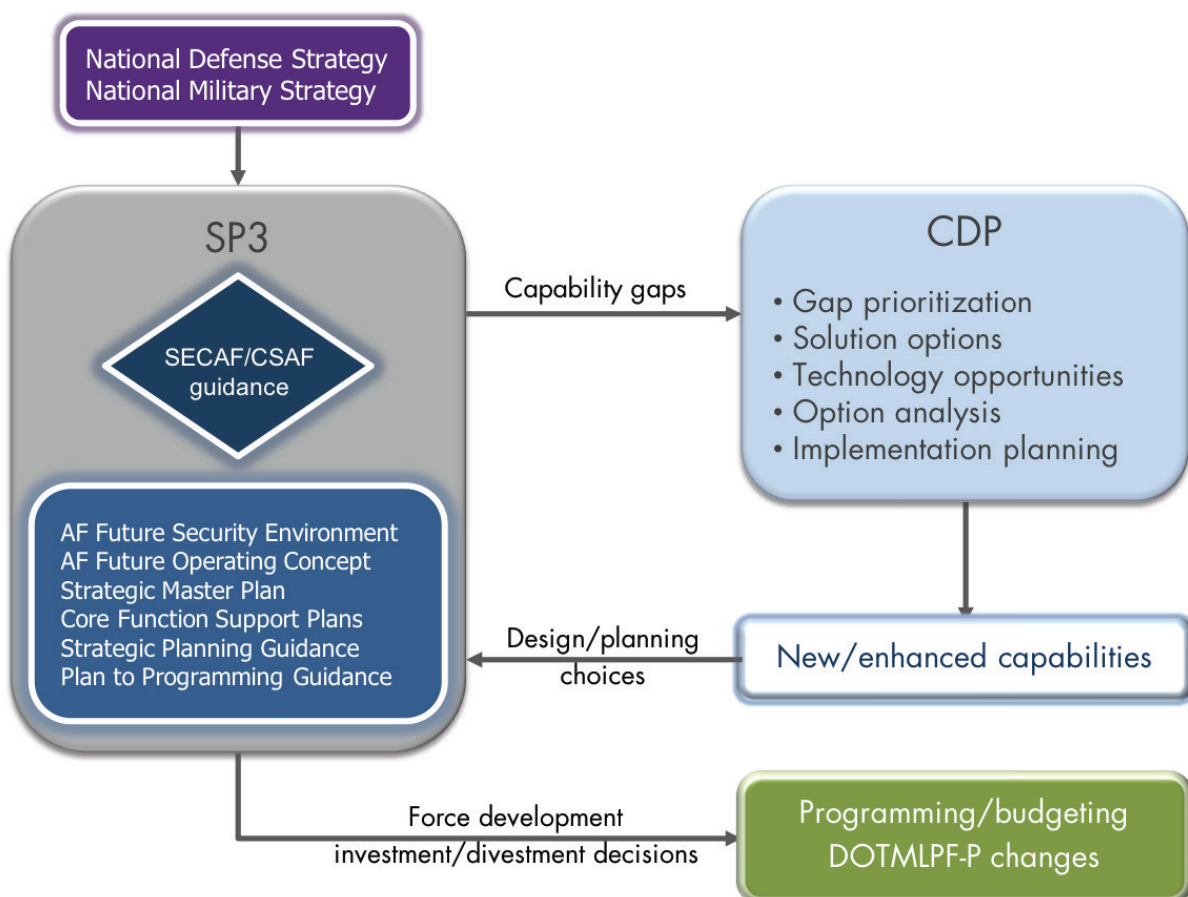
The Air Force needs capability options to execute missions in support of national defense and joint and combined operations under a wide array of contingencies. These capabilities must be responsive to changing needs. They must be affordable and adaptable enough to be modified easily or divested when no longer mission effective. They must be able to integrate seamlessly with other assets. The capability development process itself must also become more responsive, adaptable, and agile. The increasing rate of change of today's technologies and security environment is fundamentally at odds with a decades-long capability development process that often fields cumbersome, inflexible, and expensive systems. (USAF, 2015, p. 14)

The Air Force recognized the need for change in CDP and instituted a number of reforms intended to improve the CDP process. In June 2016, Air Force leadership chartered the Air Force Capability Development Council (CDC), the CDWG, and the office to support these groups, the Air Force SDPE Technology Directorate (James and Welsh, 2016). These organizations were established to institutionalize a mechanism for recognizing and acting on high-priority operational challenges and opportunities requiring Air Force senior leadership direction and aligning them with the Air Force enterprise-wide SP3 and requirements and acquisition activities. The CDC is the governance board providing direction for capability development activities across the Air Force enterprise. The CDWG supports the deliberations of the CDC at

the working level. SDPE, located at the Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base (WPAFB), was established to provide analysis in support of CDP.

Figure 2.1 shows the interaction between SP3 and CDP. CDP is intended to build the analytical bridge between capability needs and preacquisition experimentation, testing, and prototyping and to establish the viability of concepts to fill those needed capabilities (Air Force Materiel Command, 2010). Using the capability gaps that flow from the SP3, CDP is a set of processes designed to (1) set the priority in which the gaps should be addressed and divestments pursued; (2) identify the various alternatives for filling those gaps, including an analysis of trade-offs among the different alternatives; and (3) create the plan for implementing the selected approach. The main touchpoints where CDP interacts with the SP3 are in the strategy development and the Design and Planning Choices events during which strategic decisions about future force trade-offs are made.

Figure 2.1. Strategy, Planning, and Programming Process and Capability Development Planning



NOTES: SECAF = Secretary of the Air Force, CSAF = Chief of Staff of the Air Force, USAF = U.S. Air Force, DOTMLPF-P = doctrine, organization, training, material, leadership, and education, personnel, facilities—policy.

Air Force Activities to Support Capability Development Planning

In the recent past, the Air Force has utilized Capability Collaboration Teams (CCTs), ECCTs, and ECs as mechanisms to consider and evaluate options for filling capability gaps. These activities are described below, although with the establishment of AFWIC and its design teams, their future use is unclear.

Capability Collaboration Teams and Enterprise Capability Collaboration Teams

Predating the renewed focus on DP, MAJCOMs took action to fill capability gaps by establishing CCTs. These are multidisciplinary teams comprised of individuals with expertise spanning operational, acquisition, technology, systems engineering, operations research, and other disciplines. Their role is to facilitate informed decisionmaking in DP. The CCTs, however, are restricted to solutions and actions that could be taken within a single mission area focus.

With the establishment of the new CDP governance structure, the Air Force also created Enterprise ECCTs. Similar to CCTs, ECCTs focus on strategic-level capability gaps in a manner that brings together individuals and expertise from *multiple core functions* and focus areas across the Air Force enterprise. These teams employ brainstorming sessions, wargaming activities, prototyping, experimentation, and other analytic activities and methods to understand future capability needs and opportunities and then explore options to meet them. The follow-up options ECCTs explore may include, for example, further prototyping or ramped up S&T initiatives (James and Welsh, 2016). Ultimately, ECCTs aim to produce sound analysis of current or prospective capabilities and inform senior leaders of an approach to fill capability gaps, along with the level of investment required to do so.

Implementation of ECCT recommendations (sometimes called *flight plans*) has proved challenging for the Air Force, as they are fundamentally cross-enterprise and demand extensive coordination. At the present time, implementation will become a responsibility of AFWIC.

Experimentation Campaigns

Experimentation in the Air Force can be described as a set of activities that test hypotheses under controlled circumstances to gather information on new or enhanced concepts and technologies. Experiments are designed to enable innovation, address research objectives, and integrate new technologies into current and future capabilities. ECs are collections of such experiments with an overarching set of learning objectives and an experimental progression from low to high complexity and fidelity in pursuit of those objectives. Simply put, ECs are “the coordinated and phased application of experimentation tools and other analyses to identify, develop, and assess a concept” (Hencke, 2017, p. 14).

This coordinated, phased approach used in ECs leverages approaches used in military campaign planning methodologies. Campaigns begin with problem-framing sessions to explore the problem space. Problem-framing examines desired end states and identifies campaign

objectives and measures of success. After problem-framing, the campaign enters a concept identification phase to explore approaches to solving the problem. This phase utilizes workshops, tabletop exercises, and wargames in concept discovery activities to propose and assess approaches. Occasionally, it also involves modeling and simulation activities or the use of prototypes to test some initial hypotheses. The concept that emerges from the concept identification phase then undergoes a further refinement phase using all of these tools (workshops, tabletop exercises, wargames, modeling and simulation, and prototypes) with increasing complexity to create a finalized concept. These tools are used in simple scenarios, such as brainstorming exercises, and during concept discovery, and they progress in complexity up to occasional incorporation into field exercises during refinement. The final refined concept is defined in documents that communicate operational value, technological feasibility, organizational feasibility, and final recommendations on courses of action for the S&T, requirements, and capability development communities (Hencke, 2017).

Relationship Between Experimentation Campaigns and Enterprise Capability Collaboration Teams

Except where otherwise specified, the use of the term *experimentation campaign* henceforth refers exclusively to the enterprise-wide activities under the purview of SDPE. The clearest avenues for ECs to interact directly with the SP3 and DP in the recent past have been through the ECCTs and senior leaders involved in CDP decisions. Given that ECCTs are year-long processes that explore specific concepts and capabilities primarily to generate recommendations for DP and investment decisions, their short duration may sometimes leave important questions unanswered or uncertainties unexplored. The recommendations generated from these ECCTs often include recommendations to charter ECs that explore such questions or areas of uncertainty over another period of time. Senior leaders can also recommend the chartering of ECs for similar purposes independently of ECCTs when they observe uncertainties related to gaps or opportunities and desire further information to benefit decisionmakers.

The aim of experimental design is to provide replicable and technically sound quantitative data to inform decisions with a manageable level of uncertainty. SDPE staff told us that one of the main purposes of an experimentation campaign from their perspective is to reduce uncertainties, and thereby (in their view) minimize the assumptions needed in scenarios for long-term CDP. In reality, experimentation may not always lead to reduction of uncertainties. Some experiments can produce unexpected results that can at times expand uncertainty space.

Long-term decisionmaking and DP rely on assumptions about the future related to warfighting, technology readiness levels, and budgets. ECs can inform understanding of the robustness of assumptions or uncertainties concerning changes in adversary force development or unexpected game-changing technology. While it may not be necessary to change the manner in which ECs are planned and executed to account for these kinds of uncertainties, it is necessary

to ensure that results of the campaigns recognize the dependency on assumptions and are consistent with “FARness” principles described in Chapter 1 (Davis, 2014).

Strategic Development Planning and Experimentation

Since its formation, SDPE has provided analytic support for ECCTs and ECs. Air Force guidance on DP calls these two activities the “linchpin of the Air Force Capability Development Process” and states that they require attention and resources so that they can provide analytically based solutions and decisions on capability challenges (USAF, 2016b, p. 24). These activities are intended to span all current Air Force functions and warfighting domains.

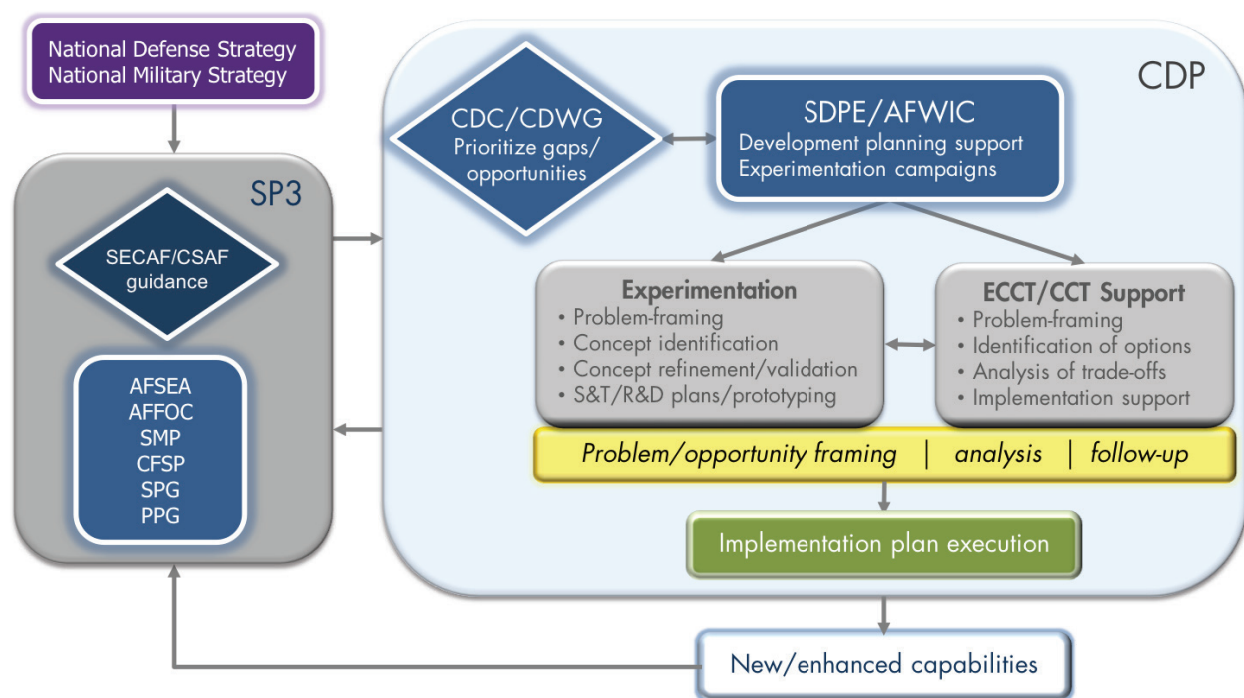
Charter

The charter directs SDPE, as an analytical support unit separate from AF/A9 (Studies and Analysis), to coordinate users and operators from all Air Force domains and communities in support of ECCTs. SDPE was also tasked with leading the analysis to improve understanding of choices available and trade-offs to be made in investment and divestment decisions. Further, the SDPE office was expected to monitor the progress of the implementation plans resulting from the ECCTs. Finally, SDPE was charged with marshaling the analytical resources and overseeing necessary Air Force experimentation activities seeking potential solutions to enterprise-wide challenges. As noted in Chapter 1, AFWIC was established in October 2017 to improve the integration of strategy, capability development, planning, programming, and budget priorities across the enterprise (USAF, 2017). In early 2018, AFWIC absorbed the CDC and CDWG as well as the innovation team that had been established under SDPE. SDPE’s prime role remains to provide analytical support to the CDP function within AFWIC. At the time of this writing, the precise division of labor between AFWIC and SDPE remains to be determined.

Planning Objectives

The primary role of SDPE is support of the CDC in facilitating DP and experimentation processes and methodologies. A simplified logic model shown in Figure 2.2 (and represented in more detail in Appendix A) presents a structured description of SDPE activities with respect to Air Force strategic DP, showing inputs and outputs of various SDPE activities in the process. This model was created using information gathered from the SDPE charter, AFGM on the SP3, other documentation from SDPE staff, and interviews with Air Force staff. The establishment of AFWIC has added some ambiguity with respect to SDPE’s lines of responsibility to ECCT support and ECs.

Figure 2.2. High-Level View of Strategic Development Planning and Experimentation Activities



NOTES: SP3 = strategy, planning, and programming process, SECAF = Secretary of the Air Force, CSAF = Chief of Staff of the Air Force, NDS = National Defense Strategy, AFSEA = Air Force Security Environment Assessment, AFFOC = Air Force Future Operating Concept, SMP = Strategic Master Plan, CFSP = Core Function Support Plan, SPG = Strategic Planning Guidance, PPG = Plan to Programming Guidance, CDP = capability development planning, CDC = Capability Development Council, CDWG = Capability Development Working Group, SDPE = Strategic Development Planning and Experimentation, S&T = science and technology, R&D = research and development, ECCT = Enterprise Capability Collaboration Team, CCT = Capability Collaboration Team.

This assessment of SDPE activities that preceded AFWIC's establishment was initially structured around the roles outlined in the charter and other founding documents. Gaps, organizational connections, and other additional information surrounding those roles defined in the charter were filled in through interviews with staff. SDPE acts in a supporting role to the CDC and CDWG in coordinating stakeholders of DP, conducting analyses, and facilitating the courses of action resulting from those analyses.

Inputs

The analytical, supporting, and coordinating activities of SDPE require many inputs from across the Air Force enterprise. There are also critical inputs from other services, the Combatant Commanders, the Secretary of Defense and his staff, and the intelligence communities. Air Force inputs include strategy documents and information on the current strategic environment, Air Force missions and capabilities, and capabilities of adversaries. It also accepts information from other ongoing Air Force DP activities, including ongoing CCTs and ECs, as well as input from

the many DP stakeholder communities across the Air Force enterprise. SDPE has also worked to assemble an inventory of various Air Force analytical tools (e.g., Advanced Framework for Simulation, Integration, and Modeling platform [AFSIM]; and the campaign-level Synthetic Theater Operations Research Model [STORM]) (Seymour, 2014) to support ECCTs and other enterprise-wide activities assigned to it by the VCSAF.

Activities to Support Enterprise Capability Collaboration Teams

SDPE's role in the DP process was initially defined in the context of its activities in support of ECCTs. Before an ECCT was chartered by the SECAF and CSAF, SDPE would solicit input and organize collaboration with stakeholders to support identification of gaps, promising emerging technologies, and opportunities resulting from new concepts. Specific activities related to identification of gaps, concepts, and opportunities would include coordination with the core functions and their individual CCTs on the gaps each of them has identified. SDPE is intended to facilitate collaboration among Air Force organizations, coordinate studies and analysis, and lead outreach to other communities within DoD, industry, academia, and federally funded research and development centers (FFRDCs). The information and recommendations on the gaps, concepts, and opportunities that would arise from SDPE's analytical work and collaboration would be briefed to the CDC, where it would be used in a senior-level decision forum to recommend new ECCTs and other Air Force priorities to SECAF and CSAF. Ultimately, this process would lead to senior leadership chartering new ECCTs and ECs, and giving direction to other DP activities. During the time when this study was underway, the CDC had completed two ECCTs: Air Superiority 2030 (AS2030) and Multidomain Command and Control (MDC2).

Once chartered, ECCTs were structured around three phases of activity: identification, analysis, and planning. In the *identification* phase, an ECCT first characterizes the threat environment and defines and clarifies the problem it is designed to solve. This step included examining friendly and adversary effects chains, identifying capability gaps and opportunities arising from emerging technologies, and performing a comprehensive review of prior analysis and reporting. This phase ends in a concept collection phase, where many concepts are submitted and initially evaluated for applicability and effectiveness, based on technology readiness level (DoD, 2009), level of gap mitigation, cost, and number of dependencies (USAF, 2016c).

During this phase, SDPE also continues the supporting work it performed before an ECCT was chartered, coordinating teams, experts, and resources from across the Air Force enterprise that perform gap and opportunity analysis and concept evaluation. SDPE supports development of the time line and the approach and marshals resources for the execution of the ECCT. Supporting analytical activities include gathering comprehensive reporting of previous studies and concepts and evaluation of other multidomain concepts. In the MDC2 ECCT, for example, SDPE aided in coordinating teams and working groups charged with threat assessment, gap assessment, and experimentation for the ECCT.

Upon completion of the identification phase, the ECCT begins the *analysis* phase. In this phase, the ECCT uses existing analytical products and tools to conduct independent modeling, simulation, and wargaming. Tabletop exercises and other experimentation activities test concepts and technologies, and models and tools for simulation-based activities are built and used to assess new concepts and technologies. These concepts and technologies are assessed for effectiveness at the engagement, mission, and campaign levels, possibly including prototypes and assessments of force structure impacts. SDPE supports this phase of the ECCT by organizing teams, coordinating with core function leads, and directing resources to facilitate and perform cross-core function trade-off analyses of alternative solutions to fill capability gaps. While SDPE did not have such analytical capabilities in-house during this research effort, it did have the situational awareness to know where to find the requisite technical support for the ECCT, either elsewhere in the Air Force or from contractors or academic researchers. Ultimately, this phase identifies and refines the most feasible concepts and technologies, such as those applicable to multidomain command and control.

The analysis phase generates strategic-level courses of action (COAs) for senior leaders. SDPE organizes and oversees analysis of COAs that will lend support to recommendations for enterprise-level decisions and technology maturation priorities. SDPE also develops the briefing of these recommendations to the CDC. Recommendations take the form of directives for action and decisions in capability development areas such as basing and logistics, find-fix-track-assess, target and engage, command and control (C2), and nonmateriel doctrine, organization, training, material, leadership and education, personnel, facilities, and policy (DOTMLPF-P). A description of the results and recommendations from the ECCT and COAs for capability development are included in a flight plan from the ECCT that describes the path forward and next steps.

Finally, in the *planning* phase, senior leadership agrees on a path forward and directs execution of COAs and flight plans. During this period, SDPE continues to offer analytical and organizational support for the teams implementing the selected COA. SDPE coordinates and oversees teams and resources, provides ongoing analytical support, and continues to foster collaboration between communities. The end outcome from SDPE activities is intended to be capability development that applies across the enterprise, has senior-leadership oversight and support, and is integrated into all elements of SP3.

Role in Experimentation in Support of Development Planning

The Air Force has renewed its focus on experimentation as part of its efforts to revitalize DP. In particular, changes to Air Force experimentation were explicitly intended to spur innovation within the Air Force DP enterprise; SDPE was recommended to take a leading role in experimentation (NASEM, 2016).

While many entities in the Air Force perform experiments in pursuit of their particular objectives, enterprise-wide ECs of the type that most concern SDPE are relatively few in

number. These ECs are chartered by the CSAF and SECAF based on recommendations generated by the ECCTs and input from other senior leaders. The intent of these campaigns, as previously discussed, is exploration of capability gaps or questions related to technology development and integration. For example, when development planners have identified an area lacking sufficient information to make recommendations, ECs are recommended to generate that information and gain insight into those areas. These campaigns reduce uncertainties in some decisions by the controlled testing of hypotheses with progressively increasing complexity and fidelity.

Activities in Support of Experimentation

We constructed the diagram shown in Figure 2.3 based on a literature review and interviews with staff at SDPE and elsewhere. This figure summarizes SDPE's interaction with and support for Air Force ECs. Even with the establishment of AFWIC, these processes and relationships remain in place with SDPE in a lead role. SDPE is responsible for designing the experimentation campaign and structuring its analytical framework to deliver data and insights based on the desired learning objectives.

Figure 2.3. Air Force Experimentation Process Flowchart



In chartering an experimentation campaign, the CDC identifies high-level learning objectives for the campaign. SDPE refines the campaign plan and designs an orchestrated set of activities intended to produce data and insights that feed the next activity in the campaign. While the EC itself has high-level learning objectives, each subactivity and experiment in the campaign will also have its own lower-level learning objectives. Each activity in an EC requires defined metrics of effectiveness or success, a plan for capturing data, and methods for analyzing the data to inform success or failure relative to the learning objectives.

Campaigns often begin with low-complexity hypothesis-testing activities such as brainstorming events and tabletop exercises. Experiments progress to activities with greater complexity, such as various levels of simulation activities or operational environment testing. In each experiment, data are collected and analyzed. The experiments are designed such that the outcomes are at least measurable, if not quantitative.

At regular intervals, these experimental results are briefed to the CDWG and subsequently the CDC. The goal of this reporting is to disseminate information and analysis from the campaign to leadership, where it can be used to further inform and reduce uncertainties in decisionmaking on investment choices, S&T program directions, and enterprise-wide program concerns.

Summary and Findings on Strategic Development Planning and Experimentation Activities and Analytical Needs

There is a sense within the Air Force that CDP as practiced through the FY 2019 budget cycle still required significant changes to make the Air Force the more agile, responsive, and innovative force it must be to accomplish its future missions. From our review of source material and expert interviews, we noted a distinct push to connect CDP efforts at SDPE with broader Air Force strategy, which itself is now closely tied to the NDS. In the past, the Air Force generated a number of strategy documents that helped guide development planning decisions, particularly the SMP, the Air Force Strategic Environment Assessment (AFSEA), and the AF FOC. SDPE staff and other development planners wanted to connect these strategy documents more concretely to the DP efforts occurring across the enterprise and noted that they should be aiding in cross-core function trade-off analyses. They further observed that this push has been received positively by partners across the enterprise. However, the ascendancy of the NDS as the guiding document across the services has largely subordinated the earlier Air Force-centric strategy documents. DP activities intersect with SP3 at several junctures, yet the specific inputs from and outputs to the SP3 remain unclear. Clarity is lacking on what analysis is involved, how recommendations are formed, and how enterprise-wide analysis should be conducted. While the senior leadership decision forums such as the Planning Choices event and the newly emerging Design Choices event seem to be advantageous venues to share results and recommendations from cross-cutting, long-range analyses performed as part of CDP, we were not able to identify formalized processes

or plans in which SDPE regularly reports results and recommendations to AFWIC or senior leadership forums in the SP3. Instances where this sharing occurred appeared to be more ad hoc in nature.

Among those interviewed, there was a consensus that SP3 needs cross-cutting analysis to better inform enterprise-wide decisionmaking and that SDPE might fill that role. The charter establishing the CDC, CDWG, and SDPE set forth broad goals and objectives for the organizations, but leaves room for interpretation of how their objectives are implemented. The organizations are envisioned as creating the robust, enterprise-wide analytic engine in support of integrated decisionmaking that the capability developing function of SP3 currently lacks. AFWIC, with the CDC and CDWG now within its core responsibilities, is intended to clarify objectives and implementation.

The AFFOC was mentioned previously as one example of a source of vision for broader, cross-cutting thinking and strategy on emerging technologies that could be “game-changers.” However, we observed that core function leads and others involved in DP below the enterprise level often did not include that vision in their technology and development road maps. We heard observations that the vision of those in the core functions is not only limited and often prone to making decisions about what is best for their core function, but also lacking broader analysis, strategy, and priorities upon which to base different decisions. SDPE staff view their role as helping to structure analysis “across the seams” in the Air Force, and present investment choices to senior leadership at regular intervals. This type of regular interaction could facilitate production of truly integrated enterprise-level priorities that can shape Air Force resource allocations for CDP.

One of the roles of SDPE in CDP, as stated in the charter, is identifying gaps and applying analysis to arrive at cross-domain solutions to fill them (James and Welsh, 2016). SDPE was created to help identify the range of possible areas to invest in by facilitating planning for capability development activities such as wargames, prototyping, and other experimentation and concept exploration exercises. However, while this is the vision for SDPE, the organization is still in the early stages of its progress toward the vision, and it is unclear how this vision meshes with the emergent activities of AFWIC. SDPE still retains the potential to be a catalyst for development of new tools for cross-cutting analysis, even in the face of the shortcomings of current tools to meet the needs of enterprise-wide integration.

Given the uncertainty inherent in planning many years into the future, SDPE’s analytic support for DP must account for uncertainty. Findings from interviews suggest that current methods and tools have neither the capability to deal with uncertainty in a robust manner nor concrete metrics for success. Staff expressed the need for an “analytic engine” that can inform trade-off decisions across core functions and incorporate effective methods of handling uncertainty. Because SDPE was established as ECCT teams were also forming, SDPE was not in a position to become a key source of analytic support for the ECCTs, though that may change as SDPE matures.

A major question for SDPE going forward relates to internal staffing and capacity to support CDP. At the time we were conducting background research on SDPE's current analytical capabilities, the analysis team consisted of four people, of whom only one had an operations research background. The team was focused primarily on working with ECCTs and experimentation campaign teams to assist in structuring their analysis and inventorying the analytical models and tools that could form the basis of a more robust analytical framework in the future. Projections of future staffing were unresolved at the time of this study.

In the next chapter, we step back and consider the functionality of CDP as it currently exists within the Air Force and identify the analytical needs to support CDP as it will need to be practiced to shape future force design.

3. Current Assessment and Aspirational View of Capability Development Planning

The approach to CDP described in Chapter 2, predating the establishment of AFWIC in early 2018, has not satisfied the expectations of stakeholders. In this chapter, we synthesize the feedback provided during our interviews and offer an aspirational view of a CDP process that addresses current shortcomings identified by interviewees. This aspirational view serves as the basis for determining the analytical needs of CDP in Chapter 4.

Assessment of Recent Capability Development Planning Efforts by the Air Force

Our analysis and discussions with the Air Force leaders involved in long-term force structure investment decisions revealed several shortcomings with the current process and supporting analysis. First, the current process does not adequately deal with uncertainties in threats, technology development, budgeting, and personnel. Second, the link between the CDP process and the programming and budgeting processes of SP3 appears tenuous. Finally, the methods for setting priorities among capability gaps and divestments and selecting which gaps will be the subject of future development are not adequately supported by analysis. Each of these points is discussed in more detail below.

Insufficient Methods to Deal with Long-Term, Deep Uncertainty

CDP in the Air Force is designed to produce the capabilities to support a future force appropriately sized and resourced for future threats within a complex and fluid policy and planning environment. But in order to do so, it must account for large and significant uncertainties that exist with respect to the international security environment, technology development, the defense budget, and acquisition time lines. These collectively fall within a category known as *deep uncertainty*, which cannot be reduced to known or agreed-upon likelihoods (defined and discussed further in the sections to follow).

The international security environment can shift in a matter of months and years, with new threats emerging and known adversaries more aggressively pursuing national strategies that run counter to the interests of the United States. Following a well-prescribed NDS provides a sense of direction and insight into priorities, but it does not reduce these uncertainties.

Similarly, current Air Force technological capabilities can become outdated or insufficient to support warfighters' needs as U.S. adversaries outspend or adopt technologies at a more rapid pace. As new technologies emerge and the battlefield evolves to different dimensions (e.g., across multiple domains combining both kinetic and nonkinetic effects), the Air Force must be

able to consider new weapons, the effects they can provide, and how their cost-to-capability trade-offs compare with more traditional weapon systems capable of delivering the same effect. The Air Force faces decisions about where to invest in the pursuit of scientific research and new technologies. The CDP process should guide Air Force decisions on where to invest research and development dollars across promising technologies at varying levels of maturity and readiness for deployment.

Federal budget uncertainty is another challenge with which the Air Force must contend. Budget delays and cuts can affect capability development time lines. Sometimes, near-term fiscal constraints erode long-term capability acquisition, forcing the Air Force to consider short-term alternatives to deliver the desired effect or accept the risk associated with the capability gap. The defense budget has lacked predictability year over year in response to congressional actions on the federal budget (Mosher, 2018). Even elements of the fiscal environment such as acquisitions that the Air Force can control and manage are laden with uncertainties. For example, the process of acquiring new weapon systems can be lengthy and suffer from production delays.

This fast-changing and unpredictable environment has implications for CDP's long-term effectiveness at identifying and developing capabilities required by the future force. Ideally, success in this regard is a process that continuously moves the Air Force toward a future force that renders it less vulnerable to future threats. Current Air Force capabilities need to be responsive to future threats at an acceptable cost. Likewise, systems may have outlived their utility relative to the cost of keeping them active or the capability they provide may be unneeded. Despite these many uncertainties, the Air Force must make informed and robust decisions about when to divest, redirect, repurpose, or modernize systems relative to future threats.

The documentation we reviewed and the interviews we conducted were consistent in observing that the capability development process should be informed by long-term Air Force strategy, as reflected in the AFSEA (USAF, 2016d), AFFOC, and Air Force SMP (or their successor products). These documents are referenced throughout the CDP process in support of the Thirty-Year Resource Allocation Plan (RAP). Our finding, however, is that current processes and decisions are not systematically accounting for deep uncertainty. Nor do they account for the resultant vulnerabilities that emerge when making plans over such a long time period. Neither the Air Force, nor any other warfighting organization, can plan with certainty over a 30-year time horizon. These deep uncertainties about the future compounds the complexity of CDP.

Instead of having a certain single future to plan for, the Air Force also contends with competing or shifting goals and priorities coming from various stakeholders. In this complicated setting, the Air Force is following the strategic priorities embedded in the new NDS released in 2018 (DoD, 2018). However, even with the NDS, the Air Force's own strategic vision may be uncertain and subject to change, more quickly now than in the past, given volatility in geopolitics and the unpredictable behavior of adversaries. The imperative to think about integrating effects

from across multiple domains (air, space, and cyber) or technology platforms further complicates the decisions. In fact, achieving effects through various means across domains is likely to become the rule rather than the exception in Air Force planning and a strong rationale for the establishment of AFWIC.

Finally, for any evaluation of investment trade-offs to have validity, the full range of potential future capabilities needs to be considered on a level analytical playing field. The Air Force requires analytical tools to accommodate uncertainties in procurement, budgets, and rates of technology development, and incorporate them into its decision analysis. Staff suggest that the Air Force currently lacks integrated decision support tools for informing trade-off decisions in the presence of uncertainties and cost implications across core functions.

Transition from Planning to Programming Is Not Well Synchronized

Because planning, programming, and acquisition processes are currently not well synchronized, several disconnects in decisionmaking have arisen (James and Welsh, 2016). Presumably, these decisions on a course of action to fill a capability gap often represent an agreement to fund actions. The CDC is then responsible for overseeing the implementation of these decisions in the RAP to ensure alignment of strategy and programming, and subsequently in the Program Objective Memorandum (POM) for the affected MAJCOMs and the core functions they represent. Interviews with Air Force staff suggest that the decisions made by the CDC governance structure do not appear to be systematically carried forward into the POM process, and integration across the Air Force functional communities is difficult to achieve through a bottom-up process. Flight plans for acquisition have proliferated (on the order of numbering 130), often outside of the view of senior staff, and flight plan execution at the MAJCOM level occasionally conflicts with Planning Choices decisions.

This challenge is further compounded by the fact that the pace of acquisition often lags behind changes in the threat environment and the rate of change in cutting-edge technologies. As a result, investment directives from the capability development process can result in programs whose utility to the Air Force is severely diminished by external forces by the time they are completed.

Priority-Setting Process for Filling Capability Gaps Is Not Aligned to Strategic Needs

A fundamental component of CDP is setting priorities on investments to fill capability gaps. By extension, this also may include decisions to terminate pursuit of some capabilities. Given limited resources to invest in future capabilities, decisions must be made in the context of future needs about which capability gaps to fill and in what order, as well as about what not to address. In the early phases of CDP, this process begins with establishing a priority list for ECCTs and experimentation campaign initiatives, key elements of SDPE's mission.

Multiple interviewees suggested that the current development process does not allow for quick identification and prioritization of gaps to be filled or capabilities to be eliminated. The selection of ECCTs and ECs, which are designed to evaluate solutions to fill identified gaps, must be more closely aligned to long-term strategic capability needs. The challenge is that the selection process appears to lack analytical rigor in terms of linking the relative importance of a particular gap to the force needed to meet future security threats. Even after potential solutions to fill a gap are found, these analyses and recommendations are not consistently informing the gap priority list, current programming decisions, or the planned capability of the future force. To mitigate the risk of ECCTs becoming obsolete because of lags in timing, this is an area that requires further development.

Extent of Deployment Costs Are Not Fully Considered

Decisions based on costs are not always straightforward. For example, weapon systems exist to provide the Air Force with the capability to perform a mission or deliver a combat effect on the adversary. Most cost analyses of weapon systems are based on total life-cycle costs (LCCs) or total costs of ownership, but these methods may in some cases miss the full costs of using the weapon systems to deliver a desired effect. The difference between the two costs structures is tied to the cost of the associated resources needed to “enable” the weapon system to deliver its intended effect in a warfighting environment.

For example, to use a fighter aircraft for a strike mission, the Air Force must deploy the aircraft to the theater, bed-down the support forces, refuel the aircraft, and provide other maintenance services. LCC analysis might consider the costs of buying the weapon system, training aircrew to fly it and maintainers to repair it, the costs of repair and depot maintenance, and the cost of providing the infrastructure at a base to host squadrons of the weapon system. However, it does not account for the cost of tankers and airlift to deploy the squadron to a contingency. Nor does it account for the increased costs associated with maintaining home-station weapon systems when the economies of scale are lost by deploying part of the unit. While estimates of these costs would need to be refined, some understanding of their approximate bounds would be useful in the earlier stages of assessing their viability

An Aspirational View of Capability Development Planning

Based on our review of the current process and supporting analytical framework, this section offers a view of an aspirational approach to CDP that could mitigate shortcomings identified above and establish desirable characteristics of analytical methods employed by SDPE.

Goals and Objectives

The goal of CDP for the future Air Force is relatively straightforward: produce the capabilities to fill the gaps between the current force and a desired future force capable of

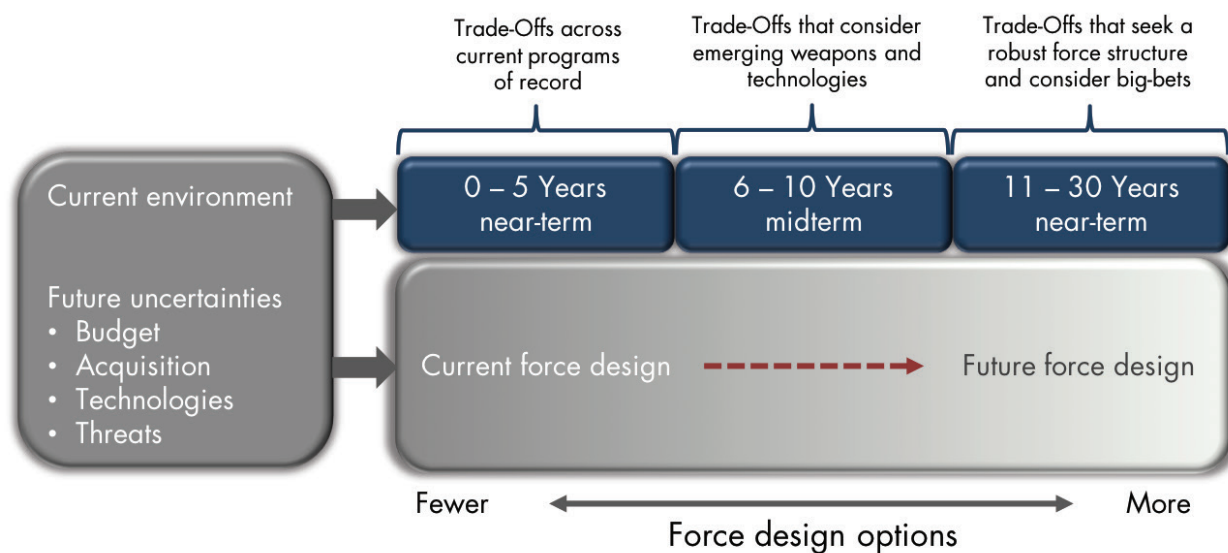
operating with joint and coalition partners to secure U.S. interests against a broad range of threats (known and unknown, real and potential). At the same time, CDP should also be identifying those capabilities that are no longer needed and can be phased out to make room in the budget for new capabilities. To achieve this goal, the capability development planners in the Air Force need to

1. demonstrate how existing and prospective capabilities might enable the desired future force to perform against a spectrum of uncertain futures: where they are most likely to succeed and where they are most likely to be vulnerable to failure
2. identify both technologies and CONOPs that have the potential to reduce vulnerabilities and exploit competitive advantages in a cost-effective manner
3. build a portfolio of capabilities to support a force that is FAR against a range of plausible future uncertainties.

Definition of Tradespace

An aspirational CDP process enables the Air Force to consider investment trade-offs year over year to move from the capabilities supporting the current force structure to capabilities supporting a range of future force structures. The challenge is to do so in a manner that is traceable and able to contend with budget and acquisition uncertainties while leveraging new technology opportunities. Figure 3.1 illustrates the growing uncertainties over time that enable greater room for trade-offs in the near, mid-, and long term in the CDP environment.

Figure 3.1. Developing the Future Force Structure in a Dynamic Capability Development Environment



Trading Off Emerging Technologies with Aging Capabilities

The investment decision tradespace will need to account for technology on-ramps and legacy system off-ramps and the timing associated with both. The CDP process should account for emerging technologies and the role they can play in filling capability gaps, or where they offer opportunities to divest legacy weapon systems that have either contributed to the capability gap (i.e., our adversaries have advanced beyond our capabilities) or have a high cost associated with delivering the intended effect. Again, a time element is associated with both causes of the gap. Emerging technologies may not be available immediately, thus requiring the Air Force to consider other near-term alternatives. Similarly, the cost of maintaining legacy systems to “inadequately” deliver a required effect may become prohibitive.

Planning Under Budget and Acquisition Uncertainty

Given the dynamics of the fiscal and acquisition processes, the Air Force must consider what short-term, fiscally responsible investments in alternative capabilities can fill the gaps resulting from acquisition delays and budget constraints. For example, how might a low-cost nonkinetic capability fill a short-term capability gap created by fiscally driven delays in acquiring a kinetic weapon system?

The time it takes to produce or make available alternative capabilities influences the options for effect delivery in any time horizon. For example, in the next five years, the Air Force might elect to employ unmanned aircraft for a light attack mission, while waiting for the next light attack aircraft to be fielded through the traditional acquisition process. Or it might opt to employ a cyber capability in the near term to defeat an integrated air defense system (IADS) while considering or developing a different kinetic system or weapon.

Over the long-term horizon (beyond two Five-Year Development Plans [FYDPs]), the Air Force should understand at what points it will need to make certain investment decisions to have the capabilities to deliver the desired effects when needed in the future by new leaders with different worldviews and facing different threats. Those time lines will likely be driven by the efficiency of acquisitions processes and availability of budget resources. At the same time, experimental efforts on emerging technologies require new analysis paradigms. An experimentation campaign is hard to integrate with a “predict and act” concept, as there is an overwhelming temptation to predict the outcome and plan on that basis. Other methods described in Chapter 4 are better suited to adapting to futures changes as new information emerges.

Planning Under Future Threat Uncertainties

As discussed earlier, the current CDP enterprise presumes a relatively high degree of certainty about future threats. In doing so, Air Force leadership lacks a view of where the targeted future force leaves the Air Force vulnerable to other potential threats not considered in the planning process. The CDP process should be positioned to deal with these vulnerabilities by

explicitly and strategically planning for adaptiveness, meaning that program portfolios should be evaluated for their ability to make the changes if they are needed to meet changing conditions.¹ Iterative analysis that informs long-term capability investment decisions should include the conditions under which assumed capabilities might fail to ensure a successful outcome in an engagement with adversaries. Further probing those vulnerabilities can also inform decisions about the lead times over which capability gaps would need to be filled if conditions trend toward realization of those problematic futures.

Analysis to Inform Capability Development Planning

Moving the Air Force from the current force structure to a future one as depicted in Figure 3.1 demands rigorous and credible analysis to back up the often contentious decisions that need to be made in the planning process. Within the structure of new strategies and concepts of operations, the analytical methods applied to this process should inform the trade-off decisions in a manner that accounts for the uncertainties in budgets and acquisition time lines, emerging technologies, and future security environments. Analysis should illuminate cost, capability, and risk trade-offs associated with the key decisions faced by Air Force leaders. Drawing on the aspirational view of CDP outlined in this chapter, the next chapter explores the elements of analytical methods that could serve those ends.

¹ Planning for strategic adaptation was discussed as early as the 1990s by Lempert, Schlesinger, and Bankes (1996).

4. Analytic Methods for Capability Development Planning

For decades, defense analysts have recognized that standard quantitative methods to evaluate and prioritize investments are unsuitable for many national security problems, which involve pervasive uncertainties and complexity (Davis, 2012, 2014; Davis, Bankes, and Egner, 2007; Davis and Kahan, 2007). Fortunately, other methods have been developed to partially meet the needs of defense planners, including methods developed outside the defense world (Dewar, 2002; Lempert, Popper, and Bankes, 2003; Davis, 2012).

In this chapter, we review some of the families of methods that have been developed to cope with both the uncertainties and the complexities that surround CDP. While the range of resource allocation problems and methods for addressing them is vast, we focus on those methods with relevance to the capability development investment problem facing SDPE in support of AFWIC, as part of its role in future force design. We then offer guidance on how methodologies can be chosen and applied, based on problem characteristics as well as institutional, resource, and other constraints.

Attributes of the Investment Problem

CDP has attributes comparable to investment problems confronting any organization dependent on advances in S&T: how to allocate a limited budget among promising but uncertain research- and development-oriented projects (e.g., basic and applied research, experimentation, and other types of developmental activities) to yield advantageous improvements in capabilities and desired mission effects. Of course, success cannot be guaranteed with any S&T activities within a particular timeframe, and their ultimate effects on future warfighting are therefore uncertain. Hence, SDPE's approach to supporting CDP is best differentiated by the nature of uncertainty and degree of complexity of each operational problem it seeks to inform.

Uncertainties

Well-defined uncertainties are those that can be objectively estimated and replicated, either as a single probability or as a probability distribution. For example, the likelihood of experiencing a car crash is easily calculable from ample historical data and can be expressed in the form of a probability distribution. Much of the academic literature regarding S&T performance metrics relies on estimating probabilities of success or failure of the research

activities within some time frame.¹ However, benefits and costs associated with these investments often are speculative to the point that planners cannot assign a probability to their success, an attribute of planning problems known as *deep uncertainty* (Davis, 2014, p. 6; Lempert, Popper, and Bankes, 2003). Deep uncertainties occur when parties to a decision do not know or cannot agree on (1) models that relate the key forces that shape the future, (2) probability distributions of key variables and parameters in these models, or (3) the value of alternative outcomes (Lempert, Popper, and Bankes, 2003). This type of uncertainty is sometimes called “Knightian uncertainty” after Frank Knight, a University of Chicago economist in the early twentieth century (Knight, 1921). For example, likelihood estimates of long-term land-use patterns, global economic growth, or long-term future warfighting conditions lack a theoretical or empirical basis and therefore would be neither reliable nor verifiable. These are deep uncertainties.

Even if the success, timing, and military end-use application of these research projects could be estimated with confidence, the security environment itself is highly uncertain as adversaries’ capabilities and CONOPs evolve and improve. Uncertainties also abound regarding deployment by either side of new or improved capabilities, which can be highly dependent on other existing or enhanced capabilities. While military planners may seek new or improved capabilities to support current CONOPs, it is also the case that new capabilities themselves can open up the possibility of novel and unexpected CONOPs that would otherwise be unattainable.

Complexities

Complexity is another critical dimension of the capability development investment problem. In its simplest definition, *complexity* refers to a system with many interacting and interdependent elements that are difficult to “describe, understand, predict, manage, design, and/or change” (Magee and de Weck, 2004, p. 2). For example, the complexity of a multidomain battlefield can be characterized by the sensitivity of outcomes to initial conditions and nonlinear interdependencies among system elements in the form of network effects, feedback loops, and adaptations. Quantitative assessment of a system with many nonlinearities is difficult, and more so when the target is to assess the value of causal links between capabilities and mission effects in an uncertain strategic environment across multiple domains.²

¹ Regarding terminology, DoD’s budget includes a research, development, testing, and evaluation (RDT&E) program with seven distinct budget activities (6.1–6.7). Three of the seven activities—6.1 (basic research), 6.2 (applied research), and 6.3 (advanced technology development)—are referred to as the S&T program.

² Complex systems are in contrast to “reductive” systems in which outcomes can be predicted in straightforward ways—for example, when looking at the performance of a stand-alone and relatively simple piece of machinery such as a diesel generator or an air conditioner for a single isolated facility.

Simultaneously, the number of options, the number of outcome metrics by which to evaluate those options, and the ease with which options can be mapped to outcome metrics contribute to the complexity of the problem. At one end of the spectrum, a problem may have a handful of options and outcome metrics and clear relationships between them. For example, the decision of whether or not to buckle one's seat belt is simple. The choices are to buckle up or not, the outcome metric is safety in the event of a crash; it is trivial to see that buckling up increases safety while not doing so lowers it. This can be determined even if the specific risk of a crash is unknown, or the degree to which buckling up increases safety is unknown. At the other end of the spectrum, a problem with many options, many outcome metrics, and unclear relationships among them would be considered highly complex. CDP is an example of such complexity in which the question is how to invest in some combination of potential R&D projects to achieve a variety of technical advancements and mission effects years down the road.

A complicated problem is not the same as a complex problem. Nason (2017, p. 93) notes that "complicated systems, by definition, adhere to a comprehensive and robust set of axioms and rules, and thus it is a matter of making sure that the proper models are being used for the situation at hand." In contrast, Nason says, "Complex systems are nuanced and require a nuanced approach. The one thing that will not work is a rigid, rules-based, complicated approach." This is an important distinction in thinking about appropriate analytical methods to apply to the SDPE problem set.

Other Aspects

The CDP investment problem has other aspects that contribute to uncertainty and complexity. For example, capabilities to achieve mission effects increasingly span multiple domains (e.g., land, air, space, and cyber) and may serve more than one function. Further, the execution of most CONOPs requires sophisticated networking of many individual technology platforms and functionality under challenging battlefield conditions.

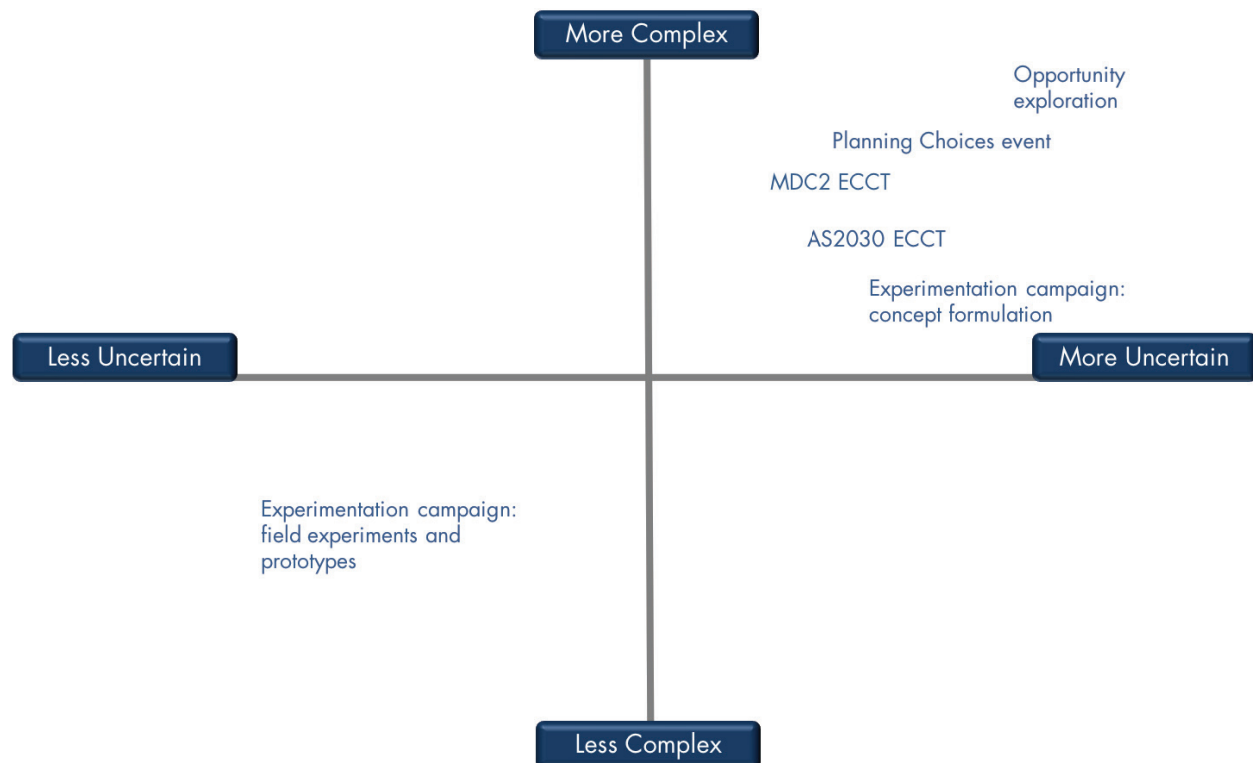
There also remains a challenge of identifying, quantifying, and reconciling multiple measures of effectiveness associated with the multiplicity of national security objectives. As Davis (2014) notes, individual measures are often incommensurate with one another and hence not amenable to consolidation. Monetizing measures of effectiveness is inappropriate for defense applications. Rather, it is the job of the analyst to help policymakers understand the trade-offs among competing objectives, however measured in qualitative or quantitative terms.

Uncertainties and Complexities Associated with Strategic Development Planning and Experimentation's Analytic Support Activities

Figure 4.1 plots several recent SDPE activities characterized by the level of uncertainty on the horizontal axis and the level of complexity on the vertical axis. Beginning in the lower left quadrant, we characterize typical field tests and prototyping ECs as being relatively less uncertain and complex compared to other activities. More generally, ECs focused on field-testing

and prototyping are included in this quadrant because they are typically executed after extensive analysis and lab testing have already been conducted. Hence, the bounds of “uncertainty space” have been narrowed from where they may have been farther upstream in the R&D process, and the questions to be answered are more focused. Testing conditions can be controlled and success rates can be quantified.

Figure 4.1. Strategic Development Planning and Experimentation Activities Characterized by Level of Uncertainty and Complexity



In contrast, activities in the upper right quadrant are both more uncertain and more complex. The extreme case is the exploration of opportunity and the pursuit of a newly emergent technology in its earliest stages of R&D, long before field tests or prototyping can even be contemplated. Less extreme than the exploration opportunity, the multidomain character and the broad reach of C2 technologies and CONOPs across all facets of Air Force operations made the MDC2 ECCT a more complex and uncertain problem. The AS2030 ECCT was tasked to identify the ways and means by which the Air Force could maintain air superiority over the next ten to 15 years, as adversaries advance in their sophistication and as the technology of various weapons platforms and their enablers evolve. Faced with relatively little knowledge of future threats, adversaries’ rate of technology development, and even the rate at which a solution could be

operationalized through acquisition process, the AS2030 ECCT also falls squarely in the upper right quadrant.

With the predominance of ECCTs and other key CDP issues falling in the upper right quadrant, we focus our subsequent discussion on analytical methods appropriate to those conditions of deep uncertainty and more complexity.

An Approach to Framing the Investment Choice Problem

Choosing an appropriate approach to the capability development investment problem begins with building a common understanding of the problem to be solved and the decision space to be explored with stakeholders. In this section, we describe a general problem-framing approach to complex resource allocation decisions under uncertainty, which precedes the choice of analyses and models.

Problem-framing is the process of building a clear, concise, and common understanding of an analytical problem and is the first step toward identifying methodologies to solve the problem. Many approaches to problem-framing have been developed over the years. A simple and effective approach often used for resource allocation problems is called “XLRM” (Lempert, Popper, and Bankes, 2003); as shown in Table 4.1, it is a way to organize the critical elements of a problem, including the following:

- the desired outcomes from the problem and what outcome metrics (M) would be used to measure whether the desired outcomes have been met
- the levers (L), options, and strategies that can be implemented to achieve the desired outcomes

Table 4.1. Uncertainties, Relationships, Strategic Levers, and Outcome Metrics Framework for Air Force Capability Development Planning Problem-Framing

Uncertainties (X)	Levers, Options, Strategies (L)
Uncertain (usually exogenous) factors and scenarios about future Air Force warfighting needs, capabilities, or conditions	Options, concepts, and strategies to develop future Air Force capabilities to meet current or future warfighting needs (some of which may have uncertainties associated with them)
Relationships (R)	Outcome Metrics (M)
Models, equations, expert views, and any other relationships that can be used to evaluate options across outcome metrics across the range of uncertainties; these relationships also have uncertainties embedded within them	Criteria by which stakeholders would evaluate levers, options, and strategies options to judge if they address needs (which also carry uncertainties)

- the exogenous (X) uncertainties that shape how well each lever would achieve the desired objectives
- the analytical relationships (R) available to evaluate the levers according to the outcome metrics under the uncertainties.

XLRM helps organize most of the relevant components of a decision analysis and is agnostic as to the particular approach that may later be applied. Scoping a problem also includes explicit decisions about the appropriate spatial and temporal resolution of the analysis and other assumptions that help to bound the scope of the problem space.

While sometimes conducted by analysts alone, problem-framing should ideally involve all the parties to a decision. Stakeholder buy-in to the answer of the question “What problem are we trying to solve?” can be critical to later buy-in to the solutions that are ultimately identified. Therefore, this step is often best undertaken in a small workshop or group discussion with decisionmakers (or their senior-most aides) and key stakeholders to the decision present. Deliberative problem-framing is particularly important in CDP in which the number of relevant stakeholders can be significant. Air Force resource allocation or experimentation problems are identified by one organization (i.e., the CDWG, CDC, and now AFWIC), solved by another (i.e., AFRL, AF/A9, SDPE, or contractors), and communicated to and acted upon by others with the Air Force (i.e., Corona, Planning Choices, CSAF), the Secretary of Defense, and Congress. Each element of the XLRM matrix in Table 4.1 warrants vigorous discussion.

Uncertainties (X)

Some uncertainties can be considered exogenous, or outside the control of the Air Force. These uncertainties can include the future security environment, acquisition performance, federal budgets, rates of maturation of technologies, and innovation cycles. Other uncertainties could be associated with the simulation and other modeling tools and relate to errors inherent in the model structure (R) and uncertainties in the estimates of parameters embedded in the models. For example, the parameter of attrition rates built into a campaign model like the Synthetic Theater Operations Research Model (STORM) (Seymour, 2014) can be subject to large errors if the adversary’s capability is poorly estimated. Still other uncertainties can be found in the efficacy and effectiveness of the levers, options, and strategies (L). Finally, outcome metrics (M) also carry uncertainties, which are related to the analytical challenges of quantifying them and their durability over the time period being analyzed. LCCs are one example of an outcome metric with large uncertainty bounds. Another example is an inadvertent misinterpretation or assumption about an adversary’s strategies or goals.

Stakeholders and decisionmakers need to be aware of these many types of uncertainties and consider their implications on results. Indeed, a crucial part of the problem-framing process is to ensure a serious debate about what dimensions of uncertainty should be addressed in the analysis. Davis (2012) provides an important synthesis of insights and lessons learned when

introducing uncertainty analysis and “preparing” for surprise in defense applications. As difficult as planning under uncertainty may be, implementation of these concepts in an operational context is even more challenging. As Davis notes (2018), decisions regarding the treatment of uncertainty in the analysis “should not be a compromise among stakeholders, but something the analytic team decides on after hearing from everyone and consulting with the CSAF.”

Metrics (M)

The definition of success in an investment strategy turns out to be one of the most difficult and most-overlooked challenges to sound planning. The simplest problem is to optimize a single objective of performance subject to a budget or cost constraint. In the real world of public policy, including defense planning, decisionmakers typically are seeking to satisfy multiple objectives, each one requiring its own metric. In the context of S&T activities, metrics can relate to the time to reach the next technology readiness level (TRL), time to advance to field experimentation, or time to success of a prototype (Mankins, 2009; DoD, 2009). Another type of metric can represent a measure of geographic diversity or a desire to maintain elements of the defense industrial base at some particular level of activity as a hedge against changing priorities.

Because of multiple and competing objectives in play, a portfolio of investment possibilities that is optimal across all objectives is difficult to identify. In contrast, Davis summarizes desirable attributes of a solution to a multi-objective problem in terms of “FARness,” or options that provide “*flexibility* to take on new or changed missions [and] objectives, . . . *adaptiveness* to new or changed circumstances, and *robustness* to adverse shocks (or even highly positive shocks)” (Davis, 2014, p. xv). Identifying solutions with FARness attributes should be the goal of CDP.

Levers (L)

Levers, *investment choices*, and *strategies* are different names for whatever the future options are that analysts and decisionmakers seek to evaluate and compare. For Air Force CDP, options can include a major infusion of research funding for particular facets of hypersonics or artificial intelligence; experimental campaigns for new position, navigation, and timing (PNT) configurations; or field-testing of light attack planes. By definition, options are within the control of the decisionmakers to implement. However, there may still be uncertainties associated with their implementation pathways or effectiveness under different scenarios.

Relationships (R)

Too often, analysts choose models before the process of problem-framing is carried out with decisionmakers and stakeholders. In fact, the ordering should be the reverse. The characteristics of the problem should shape the approach to analysis.

Relationships in Table 4.1 refer to numerical simulation models, simple analytical models, statistical functions, qualitative conceptual models, wargames, or any other representation intended to link inputs (including initial conditions and assumptions) to desired outputs of a

warfighting or enabling system. To support CDP at the enterprise level, the Air Force would ideally have a family of models capable of representing the dynamics of uncertain, complex systems and causal links between existing and new capabilities and their consequent effects across a range of scenarios. Unfortunately, such process-oriented enterprise models do not exist within the Air Force (or likely any other defense organization) at present.³ These models are difficult to build and difficult (if not impossible) to validate.⁴ For example, modeling cyber warfare and artificial intelligence applications is an active field of research but has not as yet been integrated into theater-scale modeling or gaming tools. Nonetheless, leaving these applications out of the analysis is no longer an option.

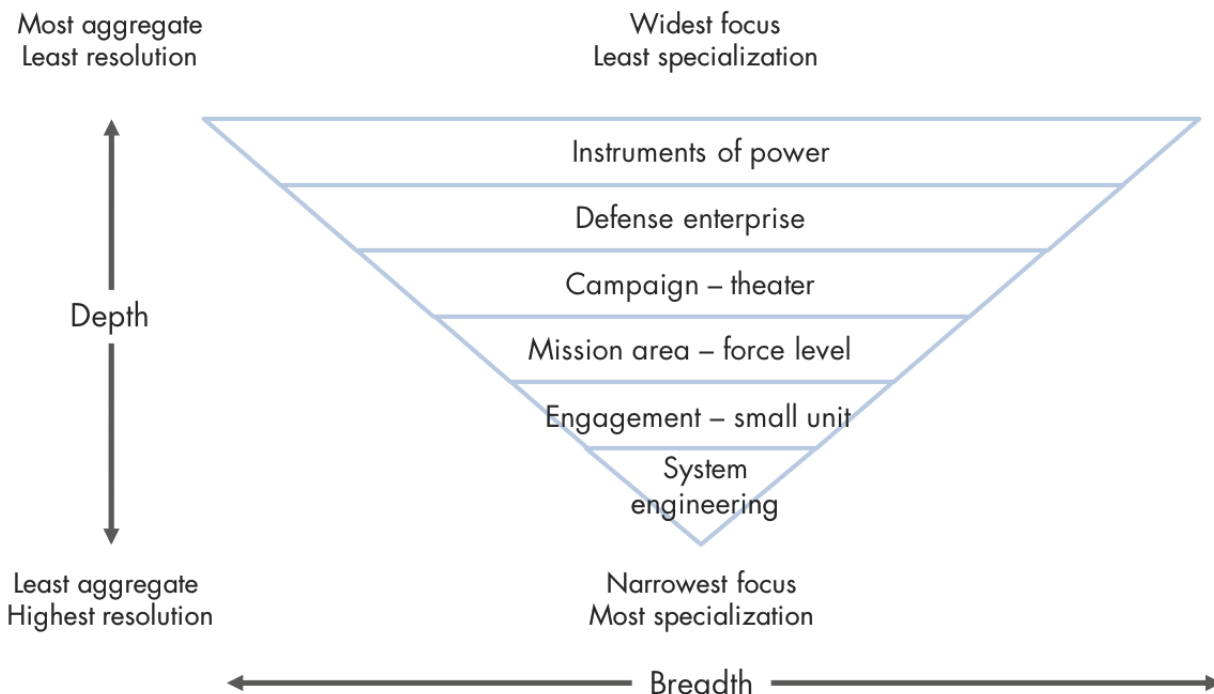
Planners are thus challenged to choose among alternative modeling or gaming approaches that can represent relationships between inputs and outputs with sufficient transparency and fidelity to support enterprise-wide decisionmaking under budget constraints and uncertainty. The Air Force and other services have been making investments to develop and refine models capable of simulating a battle in one or more domains or performance of individual weapon systems at scales below the enterprise level (Gallagher et al., 2014). Figure 4.2 depicts the common hierarchy of simulation models used in military applications, according to their ability to resolve the details of battlespace.

Use of the AFSIM platform falls somewhere between small-unit to force-level engagements in the inverted pyramid of Figure 4.2 (Clive et al., 2015). AFSIM is used in applications aimed at potential improvements in existing technologies and the expected performance of new capabilities. While AFSIM modules and other systems engineering and higher-level models designed to simulate limited engagements (below the campaign level) are invaluable from both an experimental and an operational perspective, they are not suitable for exploring higher-level options for capability development across the wider Air Force enterprise. Even STORM (Seymour, 2014), the Air Force's campaign-level model of choice, lacks sufficient resolution and flexibility to be useful for considering enterprise-wide investment options under a wide range of possible futures, at least at this point in its development.

³ One enterprise-level model in current use in Air Force to support CDP is called the Comprehensive Core Capability Risk Assessment Framework (C3RAF). C3RAF defines 42 core Air Force capabilities as its units of analysis. Expert judgment is used to identify probabilistic interdependencies among the capabilities with the end goals of assessing (a) "risk" associated with these dependencies, and (b) gaps in current capabilities (Gallagher, 2017). Following guidance from the Joint Chiefs of Staff (2016), C3RAF uses risk to mean "the probability of failing to meet mission objectives and the consequences of failing to do so" (Gallagher, 2017). A challenge for C3RAF is making a clear and transparent connection between mission risk and core capabilities; C3RAF does not attempt to simulate battlefield conditions or causal relationships.

⁴ In fact, in 2011 DoD eliminated its large campaign-modeling group; the decision was then reviewed in a congressionally mandated study (Davis, 2016).

Figure 4.2. Pyramid of Models



SOURCE: Gallagher, 2016, Figure 2.

Analytical Methods Applicable to Capability Development Planning

Different methodologies are appropriate depending upon the level of uncertainty or complexity of a problem. Quantitative risk and decision analysis often uses a “predict-then-act” approach. Our primary interest, however, is in approaches that have the capacity to deal with problems faced in CDP, which are characterized by a wider range of uncertainties and complexities. In these problems, models can still be used, but not for direct prediction; rather, they serve as a means for understanding how outcomes may be shaped by the uncertainties inherent in the inputs and the model itself. There are many variations on these methods, including those that adapt a single-objective problem structure to multi-objective applications.

Predict-Then-Act Methods

For problems where uncertainties are well defined regardless of complexity, quantitative predict-then-act methods are appropriate. Predict-then-act methods embed an assumption that the behavior of a system (e.g., a campaign or weapon platform) can be represented in mathematical terms with sufficient certainty that for a given set of inputs, the outputs or outcomes of the system can be predicted with known accuracy. The system, however defined, is assumed to be well understood and well behaved. Model errors are assumed to be negligible. In the context of

established and mature engineering systems, predict-then-act methods are common. However, for problems involving deep uncertainty, predict-then-act methods rarely suffice, because there can be little confidence in assumptions of determinism or the projections or probability distributions underpinning the analysis.

Predict-then-act methods can be deterministic or stochastic. For example, a deterministic approach estimates the performance of a new jet engine under varying atmospheric conditions using first principles and well-developed fluid mechanics and aerodynamic models.⁵ In contrast, Monte Carlo analysis describes an approach of numerically generating a probability distribution of an outcome by repeatedly and randomly sampling input parameters from probability distributions of their values (Metropolis and Ulam, 1949). Monte Carlo simulations are widely used in physical sciences, engineering, applied statistics, artificial intelligence, and other fields.

Predict-then-act methods often drive approaches to problem-solving in which a solution is sought for allocating resources in the most efficient or effective manner subject to budget or time constraints. Optimization can have single or multiple objectives. Single-objective optimization presents the fewest challenges. Operations research methods such as linear or dynamic programming and even ordinary least squares statistical regressions are methods in which single-objective optimization is applied. Multiobjective optimization techniques are designed to solve problems for which there are multiple potentially conflicting objectives and quantitative equivalencies between those objectives are difficult to establish. For example, an engineer may be seeking to design a drone that is highly maneuverable but has minimal design complexity and low cost. Using a variety of numerical techniques, analysts seek the set of alternatives that maximizes desired outcomes (Ehrgott, 2008).

Portfolio Analysis and Scorecards

Portfolio analysis techniques are another class of methods applied to CDP (Davis, Kugler, and Hillestad, 1997; Hillestad and Davis, 1998). In one paradigmatic example of this approach, Davis, Shaver, and Beck (2008) and Davis and Dreyer (2009) developed the Portfolio Analysis Tool (PAT), which helps decisionmakers assess portfolios of investment options using a

⁵ As another example, benefit-cost analysis (BCA) follows this approach. BCA, which is a common tool for many nondefense public investment choice problems, is wholly inappropriate for CDP and virtually all other defense applications. We mention it here only because of its ubiquity in many other areas of public investment. BCA requires benefits to be monetized and compared to project costs over the project lifetime, typically discounted back to present value; projects with higher net present value are favored. A portfolio of projects could be constructed from a list of highest net present value projects. This is an example of a simple, single-objective problem (maximize net present value) and entirely inconsistent with the Air Force's multiobjective investment problem, its nonmonetized metrics related to security and warfighting, and the deep uncertainties within the planning environment.

hierarchy of policy scorecards (referred to as “multicriteria portfolio analysis with ‘zoom’ capabilities”) and an interactive means of understanding how the scores were developed. To deal with uncertainties, Davis et al. (2008) describe the process of developing a “spanning set of cases” or scenarios to explore the implications of uncertainties on the outcomes of the analysis.

A portfolio-analysis method for single-objective problems, also developed at RAND, is called PortMan (Chow, 2013). PortMan is structured as a constrained optimization. In the context of CDP, the single objective of PortMan is to find the optimal means of meeting requirements using the available supply of existing or new S&T projects. Probabilities of project success are assumed to be known. However, CDP as defined in the Air Force precedes requirements and acquisition. For this reason, PortMan is not particularly well suited for accommodating the full range of uncertainties pervasive in early stages of technological development.

Decisionmaking Under Deep Uncertainty Methods

In the presence of deep uncertainty, DMDU approaches typically focus on identifying decisions that perform well across a wide range of futures, though they may not be optimal in any particular one (Davis et al., 2008). These methods include scenario planning (Kahn, 1965; Schoemaker, 1995; Schwartz, 1991); Assumption-Based Planning (Dewar, 2002); uncertainty-sensitive planning (Davis, 2003); Robust Decisionmaking (Lempert, Popper, and Bankes, 2003) and its variant, Multi-Objective Robust Decisionmaking (Kasprzyk et al., 2013); Info-Gap (Ben-Haim, 2006); and Dynamic Adaptive Policy Pathways (Haasnoot et al., 2013). All these methods, in one way or another, reverse the ordering of a traditional predict-then-act analytical approach.

Qualitative DMDU methods may be necessary for problems that are either very simple or very complex. In the former case, a quantitative approach may not be needed; in the latter case, a quantitative approach may not be possible. Quantitative DMDU methods are often appropriate for problems that face deep uncertainty but are moderately complex; in such a case, a model is needed and can be built to quantitatively describe the interactions between the problem components.

DMDU methods typically start by “stress-testing” the system of interest as it currently exists under a variety of plausible conditions, without requiring decisions or agreement up front about which conditions are more or less likely. They then evaluate decision options under many different sets of assumptions about the future. Analysts can evaluate how outcomes vary under these many different futures. Methods vary by how decision criteria may be structured to capture, for example, some or all elements of FARness, of which there are many variations.

The inverted, bottom-up process of decision analytics can help manage deep uncertainty by encouraging consensus around the approach to exploring the implications of the uncertainties on possible outcomes. Judgments about the likelihood of outcomes come at the end of the process, not the beginning. Analyses performed in this way can help decisionmakers debate important questions such as

- Are the conditions under which an option performs poorly sufficiently likely that a different option should be chosen?
- What trade-offs do decisionmakers wish to make among robustness, feasibility, and cost?
- Which options leave leaders with the most flexibility to adapt to changes in the future?

Scenario Planning

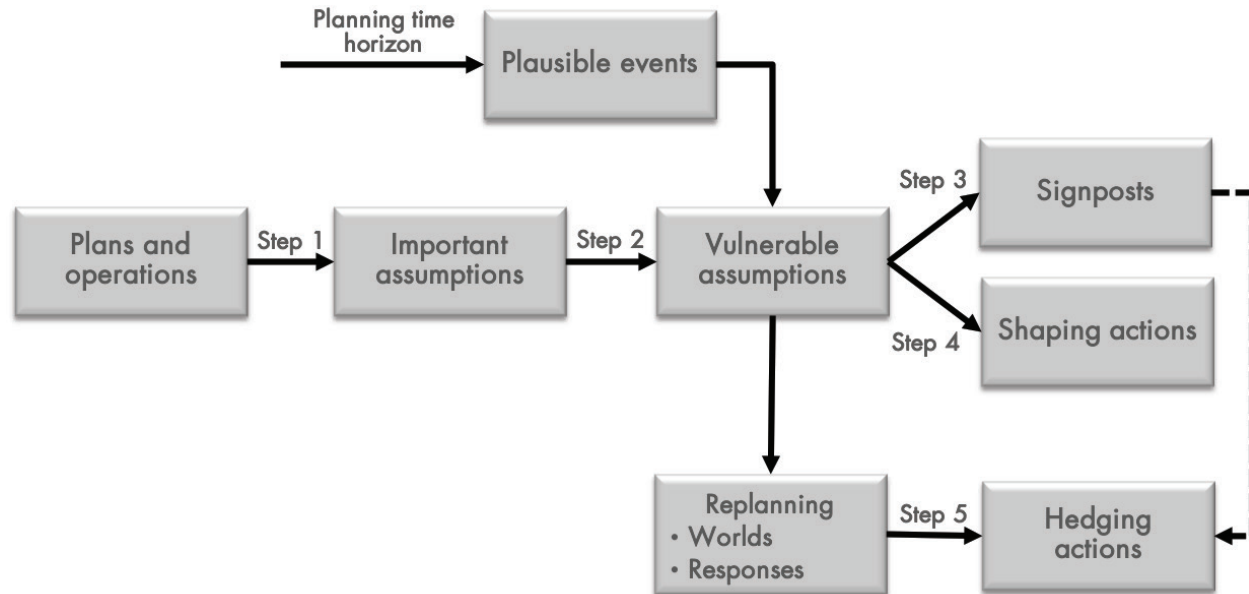
Scenario planning constructs diverse and often divergent narratives about the long-term future. Rather than tell a single story, the planners craft a suite of several complementary yet fundamentally different narratives. A family of scenarios—often three or four—is intended to span the range of plausible futures relevant to the decision at hand. The ultimate aim is for decisionmakers to use those scenarios to consider how near-term choices might shape and be shaped by those futures. (Lempert, Popper, and Bankes, 2003; Chermack, Lynham, and Ruona, 2001). Threat-based scenario planning has long been a staple of military planning albeit limited by the imagination of the planners and the typically small number of scenarios considered for analysis. Capabilities-based planning (Davis, 2002) was adopted in the early 2000s in response to the brittleness of threat-based scenario planning.

Assumption-Based Planning

ABP is another qualitative DMDU method. It is designed to help organizations systematically identify and assess vulnerabilities of explicit and implicit assumptions underlying decisions to improve existing plans and strategies (Dewar, 2002). As shown in Figure 4.3, ABP hinges on identifying *load-bearing assumptions* (assumptions that, if broken, would require a major revision of the course of action) and subsequently, the vulnerability of those load-bearing assumptions. Once identified, ABP guides organizations in determining a course of action to deal with the vulnerability of load-bearing assumptions by developing:

- **signposts**—explicit signals that may provide early warning of the vulnerability of load-bearing assumptions
- **shaping actions**—actions that attempt to control the vulnerability of load-bearing assumptions
- **hedging actions**—actions that attempt to better prepare the organization for the potential failure of a load-bearing assumption.

Figure 4.3. Steps in Assumption-Based Planning



SOURCE: Dewar et al., 1993, Figure 7.1.

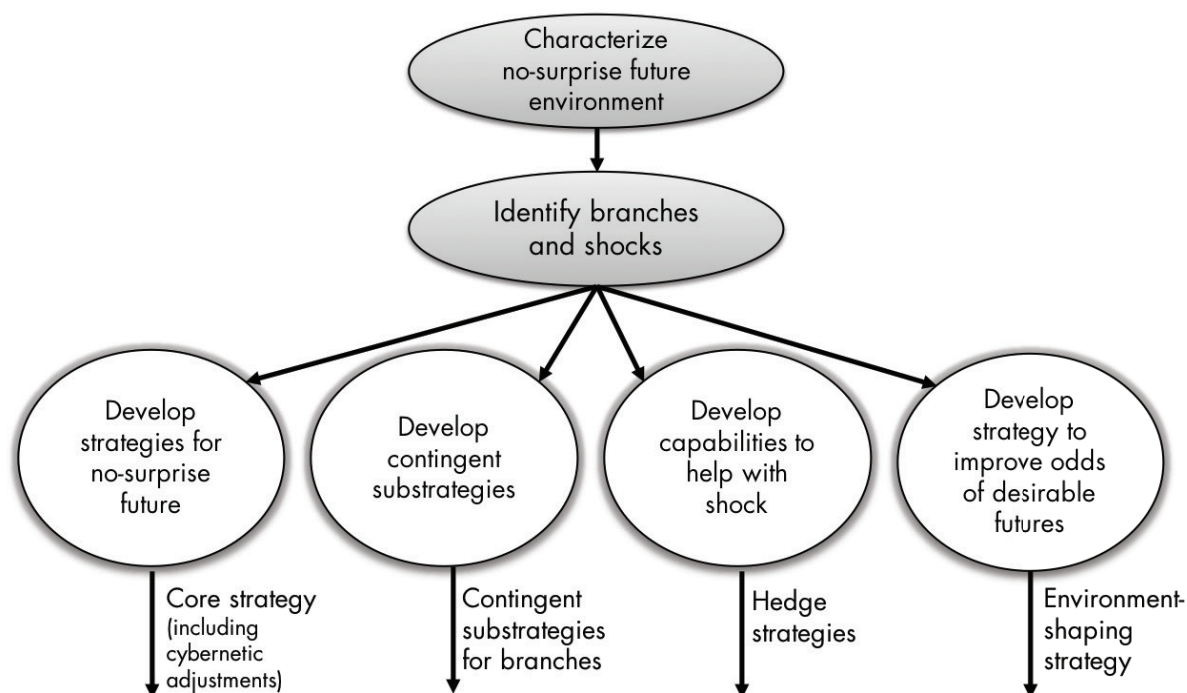
ABP is one avenue through which thinking about multiple uncertainties can be made more tractable and practicable for planners and stakeholders. ABP renders all views equally valid at the onset of analysis and thus provides a structured framing to support interactions with and among different stakeholders during the planning process.

Uncertainty-Sensitive Planning

A close relative of ABP is uncertainty-sensitive planning, intended to provide a qualitative but structured approach to building plans and strategies from scratch (Davis, 2003). As shown in Figure 4.4, this qualitative approach decomposes the possible portfolio of strategies by their purpose. This provides the backbone for capabilities-based planning in which a strategic portfolio of capabilities can be constructed to address each of the strategies, even when multiple measures of effectiveness are in play.

Davis (2003) also lays out an approach to mapping uncertainty space, addressed in more quantitative terms in the following discussion of Robust Decisionmaking.

Figure 4.4. Structure of Uncertainty-Sensitive Planning



SOURCE: Davis, 2003, Figure 5.1.

Robust Decisionmaking

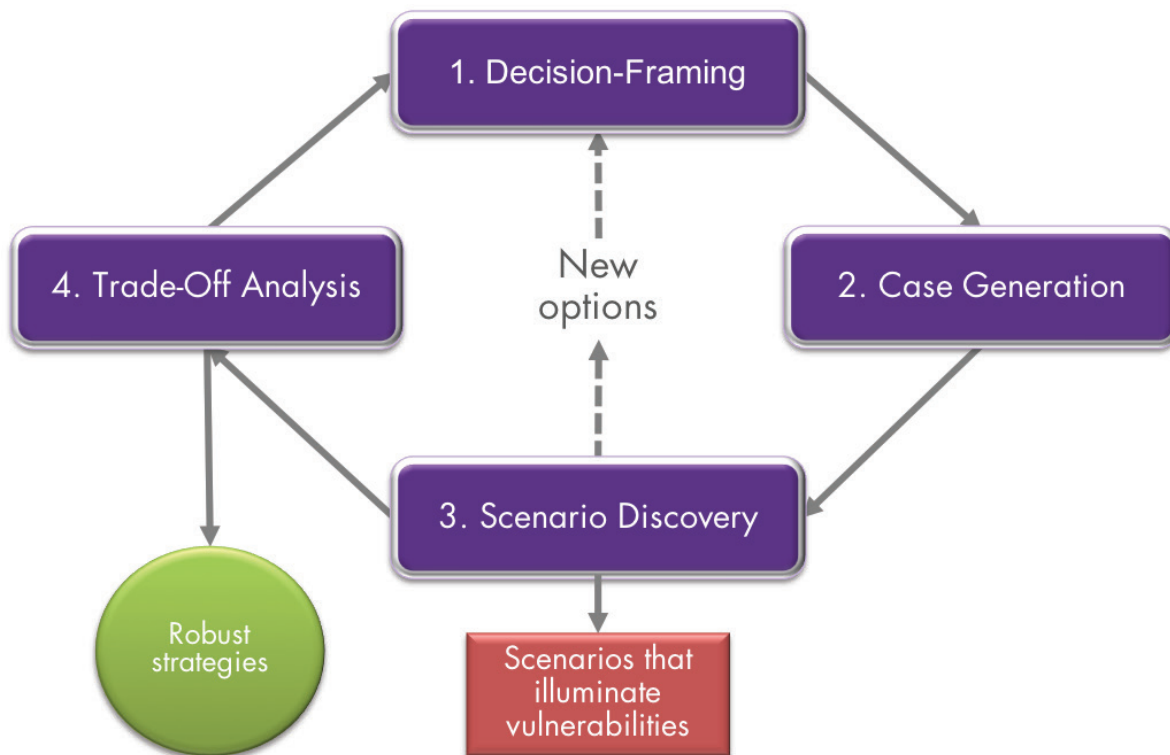
RDM is an iterative, quantitative, and participatory decision support method designed to address the challenges of planning under deep uncertainty (Bankes, 1993; Lempert, Popper, and Bankes, 2003; Groves and Lempert, 2007; Lempert et al., 2013, 2016). Rather than using models and data to assess policies under a single set of assumptions, RDM runs models over hundreds to thousands of different sets of assumptions to understand how alternative plans, strategies, operations, or technologies perform under many plausible conditions. In the absence of specific knowledge of the probability of any particular future occurring, a large number of futures is constructed by uniformly sampling across the many dimensions of uncertainty space (equivalent to a Latin hypercube experimental design). A model of the system of interest then simulates the performance of each option under these many possible future conditions. Decisionmakers identify regions in uncertainty space where outcomes are both favorable and unfavorable and seek to identify the particular conditions that influence those outcomes through a process known as *scenario discovery*.⁶ Scenario discovery leads to the identification of options or adaptations

⁶ The process of scenario discovery described here relies on intense computation to expose the vulnerabilities in the many sets of plausible futures. Another approach gaining acceptance in the DMDU community is one in which an analyst “guides” the discovery by first using simple models to target areas for deeper analysis.

that can mitigate the effects of the unfavorable conditions and lead to improved outcomes. Often, improvement in performance along one dimension—for example, more resilience of forces against air defenses—comes at additional expense. An RDM analysis enables the mapping of “tradespace,” forcing decisionmakers at that point to make some judgments about the likelihood of the “decision-relevant” scenarios identified in the discovery process.

Depending on the problem-framing, robust alternatives identified by RDM can be both flexible and adaptive, designed to evolve over time in response to new information. By embracing many plausible sets of assumptions or futures, RDM can help reduce overconfidence and the deleterious impacts of surprises, systematically include imprecise information in the analysis, and help decisionmakers and stakeholders with differing expectations about the future reach consensus on a path forward.

Figure 4.5. Iterative Process of Robust Decisionmaking



As shown in Figure 4.5, each of the four basic steps of RDM feeds the next.

- Step 1, Decision-Framing: Stakeholders identify important metrics that reflect decisionmakers’ goals, management strategies and policies (levers) considered to pursue goals, uncertain factors that may affect the ability to reach goals, and the relationships among metrics, levers, and uncertainties, typically captured within one or more simulation models.

- Step 2, Case Generation: Some type of model of the system of interest is used to test the full range of effects from existing and potential capabilities and force structures against a wide range of plausible future conditions.
- Step 3, Vulnerability Assessment and Scenario Discovery: Decision-relevant scenarios where vulnerabilities are highest are identified, enabling identification of strategies or investments that might be most effective at mitigating or neutralizing the effects of these challenging conditions. (Note that these scenarios are not the same as DoD-prescribed scenario narratives of single points in the future.) The search for vulnerabilities can be aided by analysts manually identifying the types of vulnerabilities to search for. Further, conducting an initial exploration using relatively simple models is an efficient and transparent way to gain initial insights that could then be explored in more depth through higher-resolution models. This step then provides the essential inputs to the next step of a trade-off analysis where alternative investments, as identified by Air Force stakeholders, can be simulated to assess their effectiveness in reducing vulnerabilities highlighted in scenario discovery.
- Step 4, Trade-Off Analysis: Using robustness as the primary decision criterion, decisionmakers attempt to converge on an investment strategy that will perform well over the scenarios of interest. The analysis should be structured to be adaptive as opportunities, threats, capabilities, and bounds on uncertainties change over time.

Multi-Objective Robust Decisionmaking

Multi-Objective Robust Decisionmaking (MORDM) (Kasprzyk et al., 2013) augments RDM by using advanced optimization tools to search for and identify the best-performing strategy under any given future and combination of preferences across multiple decision metrics. Decisionmakers and stakeholders can then interactively explore this “Pareto surface” to help identify strategies more robust to uncertainty while also resolving trade-offs among other goals, recognizing that there is no one “optimal” solution.

Info-Gap

As described by Ben-Haim and Demertzis (2015, p. 4), “An info-gap is the disparity between what you *do* know and what you ‘*need to know*’ in order to make a reliable or responsible decision.” The Info-Gap approach helps decisionmakers cope with deep uncertainty (i.e., when uncertainties cannot be characterized a priori by probabilities) and find solutions that are robust across a wide range of possible future conditions. This approach to coping with deep uncertainty is sometimes described as “robust satisficing” and “good enough” (Ben-Haim and Demertzis, 2015, p. 5).

An Info-Gap analysis produces a graph showing the performance that can be achieved on one axis, as a function of uncertainty on the other axis. Like RDM, Info-Gap does not provide decisionmakers with a single solution; rather, it seeks to inform decisionmakers about trade-offs,

risks, and vulnerabilities. In contrast to RDM, this approach does require planners or decisionmakers to make an *a priori* judgement about the worst-case scenario that could be tolerated.

Dynamic Adaptive Pathways Planning

Another DMDU approach is Dynamic Adaptive Pathways Planning (DAPP) (Haasnoot et al., 2013). DAPP is not directly comparable in its analytical rigor to either RDM or Info-Gap; rather, it represents a structured approach to addressing the time-dependency of many resource allocation problems. With the DAPP approach, a plan is conceptualized as a series of actions over time (pathways). Consistent with an adaptive form of RDM, the essence is the proactive planning for flexible adaptation over time, in response to how the future actually unfolds (Haasnoot et al., 2013). The DAPP approach starts from the premise that policies or strategies have a design life and might fail as the operating conditions change (Kwadijk et al., 2010). Once policies or strategies fail, additional actions are needed to achieve objectives, and a series of pathways emerge; at predetermined trigger points, the course can change while still achieving the objectives and avoiding overcommitment to a course of action in the presence of deep uncertainties. By exploring different pathways and considering path-dependency of actions, an adaptive plan can be designed that includes short-term actions and long-term options. The plan is monitored for signals that indicate when the next step of a pathway should be implemented or whether reassessment of the plan is needed.

Implications for the Air Force of Adopting Decisionmaking Under Deep Uncertainty Methods

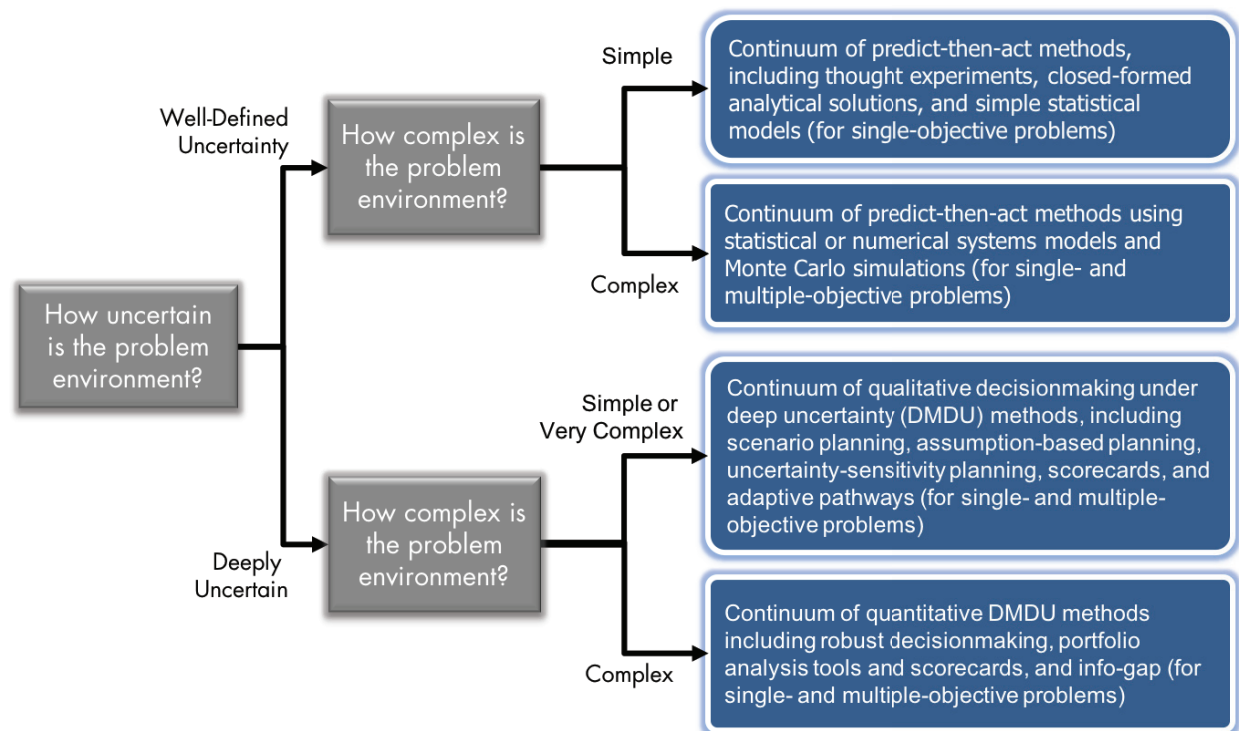
To understand weapons and other engineered systems performance, the Air Force utilizes well-accepted approaches to design, experimentation, and analysis. However, current analyses and models to assess long-term investment decisions to develop new capabilities are not systematically accounting for uncertainties of future threats, technological change, acquisition, and budget—and the vulnerabilities in future performance these uncertainties may expose. Uncertainty arises from the unpredictability of future threats, operational concepts, technologies, and budgets, as well as fundamental lack of a way to capture the complexity of warfighting. Complexity relates to the number of elements in a system and their interdependencies, network effects, feedbacks, and other difficult-to-model relationships. We distinguish *complex* from *very complex* problems by their amenability to high-resolution mathematical modeling. A complex problem could be modeled with some degree of fidelity and validation; a very complex problem would largely defy such a modeling approach and instead be best approached through thought experiments or other qualitative methods. Both complexity and uncertainty drive the choice of analytical approach.

As summarized in Figure 4.6, a “choice of methods” decision tree can guide selection of methods to inform decisions of varying levels of uncertainty and complexity. The decision tree presents the questions “How uncertain is the problem environment?” and “How complex is the problem?” The answers shape whether qualitative or quantitative predict-then-act or DMDU methods are appropriate.

While scenario planning and other qualitative DMDU methods have been available and applied for decades, quantitative DMDU methods have been enabled only recently by the growing availability of high-performance computational resources. These methods have been applied with success in nondefense policy areas such as infrastructure planning, energy development, and water resources planning; for an example of the latter, see Groves et al. (2013). However, their uptake within the defense policy community has been slower (Danzig, 2011; Lempert et al., 2008, 2016).

Not all problems warrant these sophisticated approaches. Simple problems can be analyzed using both qualitative and quantitative methods. Good defense-related examples of quantitative methods applied to relatively simple problems can be found in Kent, DeValk, and Thaler (1988) and Ochmanek et al. (1998). Morgan and Henrion (1992) provide a comprehensive overview of methods.

Figure 4.6. Choice of Methods Framework



DMDU methods offer numerous advantages over predict-then-act approaches. First, predict-then-act approaches require agreement among the parties up front on decision-relevant scenarios—even before they have had the benefit of the analysis to inform their understanding of what elements of the future environment are most consequential to their decisions. Second, assumptions can be buried in simulation model codes and treated as certainties when in fact their actual value is a key uncertainty. Third, DMDU methods are exploratory by design and intended to be run in a participatory and iterative mode. This has the effect of explicitly shifting the burden of making value judgments with respect to trade-offs and risk acceptance to the decisionmakers, which is where it belongs.

Successful implementation for long-term planning rests on a number of requirements beyond raw computing power. Even for problems well suited for DMDU, there may be institutional challenges or constraints to mainstreaming these new approaches. Here, we discuss some of these considerations, with a focus on what would be needed for successful adoption in support of Air Force CDP.⁷

Availability of Appropriate Models, Data, and Computing Power

Quantitative DMDU methods are generally designed to employ existing models and data. Thus, in cases where decisionmakers are already using quantitative analysis to inform their choices, these methods can augment such activities to provide a richer understanding of uncertainty and the best ways to respond to it. The aim is to stress-test a strategy or system under many possible combinations of future conditions across the multiple dimensions of uncertainty.

Models to support DMDU analyses can be simple or complex. As an example of a simple model, an analyst using a spreadsheet model to compare the cost-benefit ratios of alternative investments in munitions could use RDM to run the spreadsheet over many thousands of combinations of assumptions and to identify those futures where one investment strategy was consistently more cost effective than another. RAND researchers Joel Predd and Igor Mikolic-Torreira took a similar approach in an analysis for DoD's Cost Assessment and Program Evaluation, using RDM with a relatively simple force structure model focused on a few key variables that could capture significant changes in capabilities about which they had knowledge (interview with Mikolic-Torreira, January 9, 2018).

At the present time, the Air Force has many campaign- and mission-level models, as well as models designed to simulate the performance of individual weapon systems. Quantitative approaches to DMDU would require models that represent complex or multipart systems. This could entail taking existing models, possibly of different resolutions in space, time, and effects, and then “coupling” them together to allow for automated simulations across a range of

⁷ These observations are adapted from those made by Lempert et al. (2013) regarding the application of Robust Decisionmaking in developing country contexts.

uncertainties and policy levers (Groves, Sharon, and Knopman, 2012). For instance, Lempert et al. (2016) developed a campaign-level simulator and coupled it with an existing weapons-on-target model in order to pilot-test RDM methods for munitions acquisition planning.

In this approach, DMDU applied to Air Force CDP would require coupling existing models simulating force generation, acquisition, campaign fighting, and weapons effects; uncertainties and policy levers could influence the system at each of these levels and would need to be considered within a single modeling framework. Alternately, existing models could be expanded, or new models developed, in order to represent a systems perspective at the appropriate level of detail. In any event, technically credible quantitative modeling of warfighting capabilities at an enterprise level is extremely difficult and has yet to be achieved.

Another approach that has been used with success is sometimes called *multiresolution modeling* (Davis, 2014). Multiresolution modeling takes a top-down perspective, beginning with a single aggregated model with relatively few variables (for example, less than ten). Using such a model, an exploratory analysis of the solution space under different future conditions could reveal vulnerabilities in CONOPs and thus point toward areas in need of further study. Those can then be selectively pursued in detail. For example, studying a single variable or model parameter in more detail may require another simple, but narrowly scoped model, or it may require a more detailed approach, such as a one-on-one engagement model. As another example, a specialized interface might allow a top-down uncertainty analysis with STORM, which could be made possible by turning STORM into a lower-resolution model for this purpose.

As modeling platforms with coupled or nested models within them grow in complexity, another potential implementation barrier could arise. Quantitative DMDU methods typically require more computer processor time to conduct hundreds to thousands of runs than does a traditional approach and more computer storage to save the results. In practice, these constraints are becoming less significant over time. Analysts with spreadsheet models will generally have more-than-sufficient storage and processing power on a laptop to run the spreadsheet thousands of times. Analysts running a complicated simulation model may require hundreds or thousands of processors to run their models over numerous cases. These are increasingly available through commercial cloud computing services, and those with the skills to build complicated models can also access such multiprocessor systems.

Configuring a model to run over hundreds to thousands of cases, however, often represents the greater challenge. For instance, staff skilled at developing cost-benefit spreadsheets may not know how to run the spreadsheet automatically over thousands of cases. Complex models may have an input file structure that makes it difficult to run thousands of cases efficiently. Both situations may require training and some reworking of computer code to enable analysts to generate and batch runs. Fortunately, this software and training can be a sound investment because of its utility in a wide range of analyses.

A Different Way of Thinking About Problem-Solving

Perhaps the most significant implementation challenges of DMDU methods arise because they represent a new way of thinking about how near-term actions can best manage future risks. Analysts are generally trained in predictive thinking, and the decisionmakers they inform often expect predictive quantitative information. DMDU answers a fundamentally different question. Rather than ask, “What will happen?” DMDU allows analysts and decisionmakers to ask, “What should we do today to most effectively manage the full range of events that might happen in the future?”

Rather than driving to a solution as a result of the analysis, DMDU methods provide stakeholders and decisionmakers with a more informed tradespace. By exposing vulnerabilities of different options under different scenarios, such methods can enable stakeholders to engage in a rich dialogue about which risks or vulnerabilities are acceptable, and also return to assumptions made in framing the problem. In contrast, the current SP3 process (described in Chapter 2) follows the predict-then-act approach by beginning with an identification phase to characterize the problem or threat first, thereby assuming a level of predictability that is hard to justify in a turbulent world.

Another important distinction is that DMDU methods do not drive to a particular solution or “optimal answer.” Instead, they are a tool for facilitating an informed discussion among decisionmakers and stakeholders about the consequences and benefits of their value judgments across their multiple objectives. These methods thus focus on characterizing decision tradespace and thus enable a rich dialogue about what vulnerabilities and risks are acceptable in return for expanded opportunities and benefits.

Using DMDU methods requires training for analysts and a path by which organizations become comfortable using new and more effective types of quantitative information. Prior experience with the adoption of DMDU provides examples of how organizations in developing countries can become comfortable using RDM. For the Air Force, one successful path might involve conducting a demonstration project in parallel to its regular planning activities. Once the demonstration is complete, the Air Force could use this experience to begin to fold the new methods into its planning.

Summary of Requirements for Decisionmaking Under Deep Uncertainty Applications

Here we summarize the key points drawn from the discussion of methods and challenges in this chapter.

- An interactive problem-framing exercise is an essential first step that focuses the minds of senior leadership and stakeholders on an understanding of what questions are being asked and strategic objectives to be achieved. Such an exercise also is essential to capture multiple perspectives among stakeholders with legitimate differences.

- Analysis should begin with a conceptual model of the entire system before decisions are made about the choice of specific modeling tools. The conceptual model can then be decomposed to multiple levels of resolution, thus allowing capability development issues to be discussed and analyzed at different levels of detail.
- Exploratory analysis can provide insights into how to define uncertainty space and identify “spanning sets” of conditions to evaluate new CONOPs and systems. It can also be a means of considering adaptive pathways for capability development, informed by new information from ECs and other S&T activities.
- In strategic-level work such as CDP, investments are best viewed as *sets* of initiatives that contribute to multiple objectives. The task becomes one of “balancing” the portfolio satisfactorily across the multiple and usually competing objectives. Optimal solutions are not possible under these conditions. Instead, analysts should seek to illuminate a choice set of FAR solutions for consideration by decisionmakers.
- Analysis in support of CDP should be directed toward helping policymakers find robust strategies (those with the FARness property).

Steps Toward an Air Force Capability Development Planning Application

SDPE has the opportunity to support the adoption of methods for framing and analyzing capability development investment choices that appropriately account for uncertainties. As described in the next chapter, a decision-framing exercise followed by an application of assumption-based planning could provide insights to senior leaders about how different investment portfolios could perform under a wide range of uncertainties. We describe the results from an internal decision-framing workshop conducted at RAND with experts on Air Force planning, technology development, and simulation modeling. This workshop helped to illuminate what would be entailed to successfully conduct a DMDU pilot, as well as what additional institutional steps might be needed to incorporate DMDU approaches into regular practice for SDPE or AFWIC.

5. Decision-Framing Exercise

RAND conducted an internal workshop to explore the dynamics of applying a DMDU method to the CDP enterprise. We focused the workshop on the exercise of developing an XLRM matrix (Table 4.1), as described in Chapter 4, which would set the stage for choosing a suitable qualitative approach, such as ABP, which could be most easily executed at this time. The approach, discussion, insights, and outcomes of the workshop are summarized here.

Workshop Process

Eight RAND analysts who were not part of the project team were selected to participate on the basis of their familiarity with strategic planning, programming, and force structure design in the Air Force and other services. Participants were asked to play the role of analysts advising the CDC or AFWIC on how to frame an analysis of a capability development problem using one of the DMDU methods such as RDM. To set the stage, we presented participants much of the information found in Chapters 2 and 3 of this report. We then guided the participants through each element of the XLRM framework, starting with metrics, followed by levers, uncertainties, and relationships. When resource allocations are at stake, the success of supporting analysis of this kind is highly dependent on stakeholders working from a common and agreed-upon understanding of the problem-framing process. This is what the XLRM workshop is designed to produce.

The workshop with RAND participants was conducted over one day, which was insufficient time for clarifying and discussing all inputs from participants. An actual XLRM workshop to frame DMDU analysis of the Air Force's long-term capability development challenge would involve CDP stakeholders and would require at minimum two days. Such a workshop would require more time to probe the important dimensions of the problem space more deeply, particularly the way in which different types of uncertainties discussed in Chapter 4 might be addressed most appropriately. The role of the analysts would be to help stakeholders reach some consensus on the basic elements of the framing, and then advise senior leaders on a tractable approach to problem-framing—all before launching into a more in-depth analysis.

Summary of Results

Table 5.1 provides an overview of workshop results, discussed in more detail in the following sections (moving clockwise in the matrix). Woven into these discussions are insights related to the XLRM framework elements garnered through conversations with Air Force leaders and analysts during the course of our study. Note that our one-day workshop with RAND participants did not afford time to clarify all of the entries to the XLRM matrix in Table 5.1, some of which are at fairly high levels of abstraction. The text that follows reflects these limits.

Table 5.1. Notional Uncertainties, Relationships, Strategic Levers, and Outcome Metrics Framework for Capability Development Planning

Uncertainties (X)	Levers, Options, Strategies (L)
Security environment (e.g., nature of conflict, partnerships, adversary intent)	Force structure choices
Domestic and foreign policy (e.g., political risk tolerance)	Investment
DoD strategy	Divestment
Attribution/targeting	Modernization strategy
Baseline support for and from other services	Enhance existing capabilities
Institutional capabilities to execute strategy	Acquire new capabilities
Air Force operations	Extent and tempo of experimentation
Operational strategy with constraints ^a	Acquisition strategy/approach
Basing strategy ^a	
Readiness level ^a	
Acquisition performance	
Availability of deployable technologies	
Air Force budget	
Relationships/Models (R)	Outcome Metrics (M)
Campaign models	Cost
STORM	LCCs of buying and owning force structure
SUPPRESSOR	Collateral mission effect/kill-chain costs beyond
THUNDER	LCCs of <i>using</i> force structure
Acquisition cycle models	Operational success
Combat effects models	Time to win
AFSIM platform	Rate of attrition
BRAWLER	Damage to adversary (conditional on adversary and situation)
Cost-estimation models	Collateral damage
LCCs	
Mission effects/kill-chain costs	Deterrence (absence of conflict)

NOTE: ^a Operational strategy with constraints, basing strategy, and readiness level could also be treated as levers in the context of the CDP problem-framing exercise. It is not unusual to have uncertainties and levers treated interchangeably.

Uncertainties

There are a number of uncertainties associated with CDP and long-term investment decisions. Those uncertainties span the future security environment, acquisition performance, federal budgets, rates of maturation of technologies, and innovation cycles. For example, major uncertainties in the state of the future security environment could include potential threats and adversaries, their intent, and the state of geopolitical relations in which future military operations might be conducted. DoD recently published a new NDS (DoD, 2018), which outlines the set of near- to midterm threats and establishes priorities for how the military services will respond to those threats. In the past, the Air Force separately published the AFSEA (USAF, 2016b), which outlined a range of potential challenges and adversarial environments that the Air Force might

face in the future. In an RDM or other DMDU analysis, capability development, long-term investment decisions, and the future force they would support could be evaluated against the range of plausible futures highlighted in the AFSEA or other similar DoD or Air Force threat-assessment documents.

In reality, the specific sequence, timing, and nature of conflicts the Air Force could face in future years is itself uncertain. Using an approach similar to Lempert et al. (2016), a wide range of randomly generated sequences of conflicts of differing type and scale could be considered, influenced by the uncertainties of the security environment and campaign strategy noted above. This approach would then operationalize the long-term uncertainties into a series of “what-if” future pathways.

Closely associated with the future security environment are the uncertainties surrounding domestic and foreign policy arising from changes in presidential leadership and changes in the composition and leadership of the U.S. Congress. The most recent NDS reflects a shift from the previous administration in investment priorities for DoD, particularly with respect to the emphasis on Russia and China. This extends to decisions on the Air Force budget made by the president and Congress each year: Budget levels for DoD and the Air Force have varied and could continue to vary significantly over time, which can have a significant influence on successful CDP intended to set forth a multiyear investment/divestment strategy.

Other uncertainties, not related to the security environment, are tied to the Air Force’s ability to plan, design, and acquire the future force it needs. The process for acquiring new weapon systems is lengthy and regularly faces delays and price overruns. Delays can be caused by changes in requirements and budgets, technical barriers, and production delays by the contractor. Additionally, the rate of maturation in emerging technologies can be highly variable and unpredictable, and for this reason, technology readiness represents another uncertainty associated with capability development.

Finally, three additional uncertainties that the Air Force could face are more operational in focus: operational strategy, basing strategy, and readiness level. With respect to operational strategy, combatant commanders (COCOMs) may consider different approaches to employing combat forces (e.g., stand-in or stand-off), how they operate in coordination with other services’ combat forces, and other elements of engaging in combat. The Air Force must contend with these uncertainties as it considers future capabilities. Basing strategy is also closely related to operational strategy. A larger overseas presence might be needed to execute operational strategies that rely on speed of response. The cost of additional overseas bases would have to be weighed against the effectiveness that alternative force structures might bring. Finally, the Air Force’s level of readiness is another uncertainty that could enable or constrain options for future capabilities. The decision to maintain a high level of readiness could come at the expense of acquiring a new weapon system on a particular time line or an acquisition strategy could constrain readiness, with either circumstance depending on budget constraints.

In conducting an RDM or other DMDU analysis for capability development, varying levels of each of these uncertainties could be represented within a simulation model (e.g., as a model parameter or constraint) and combined with other uncertain factors to construct a wide range of possible cases over which the vulnerability of future force structures could be estimated.

Strategy Levers

The levers in CDP are force structure choices, as well as strategies for modernization, acquisition, basing, and operations that the Air Force employs to meet current or future warfighting needs. Many of the levers are related to each other and can be adjusted depending on which of the metrics (discussed next) the Air Force chooses to prioritize. ECs will play a vital role in refining the analysis of attributes and effects that could be achieved with specific levers such as CONOPs, weapons platforms, munitions, and the wide range of enabling technologies related to communications and PNT.

The primary class of levers, and the one at the heart of capability development, is the Air Force force structure. The force structure consists of combat weapon systems platforms and associated enabling weapon systems (e.g., C2 systems, intelligence, surveillance, and reconnaissance [ISR] systems), institutional capabilities (e.g., base infrastructure systems, communication networks), and the personnel associated with each of these categories. To produce a force capable of succeeding against a range of plausible future threats, the Air Force needs to deliver particular combat effects. For example, there are several options it could choose for suppressing enemy air defenses to include kinetic effects using manned aircraft, kinetic effects using unmanned aircraft, nonkinetic effects using cyber capabilities, or some mix of each. Options could derive from emerging technologies or enhancements of existing platforms through activities such as a Service Life Extension Program (SLEP). The Air Force might also consider whether an existing weapon system platform could be repurposed to expand its capability and enable it to deliver the needed effect.

Adding to the existing force structure is one possibility, but as important are decisions about divestment as a means of shaping the future force structure. Retiring aging aircraft and terminating acquisition programs can enable the Air Force achieve the force it needs by freeing up resources that would otherwise be consumed by systems with diminishing or no remaining value. Selecting not to invest in a particular emerging technology is also a key decision in CDP.

Closely related to force structure and modernization options is another lever related to the choice of an approach for acquiring systems. The traditional Air Force acquisition process (i.e., requirements analysis, analysis of alternatives, source selection, production, testing, and fielding) is lengthy, and the time from deciding to acquiring a new weapon system to the time it is operational has taken decades in the past. New approaches recently approved, some of which are geared to commercial off-the-shelf acquisition, are intended to accelerate the time to acquire new systems. These new approaches could provide the Air Force with greater agility in responding to changes in the security environment. Another lever would be to divert resources from long-run

acquisition programs to more flexible funding that could be applied to commercial technologies on shorter contracting cycles.

Many of these levers are interrelated. The challenge for the Air Force is deciding which levers to pull over what periods of time to produce a future force structure that reduces vulnerabilities and increases opportunities against adversaries across a wide range of plausible future threats.

Outcome Metrics

Defining useful outcome metrics is arguably the most important step in the decision-framing process, because it sets the terms of engagement between the values and preferences of decisionmakers and the effects they seek to achieve with a future force structure. Workshop participants identified three key outcomes measures for an in-depth CDP analysis: cost, operational success, and deterrence.

Two related cost metrics were discussed: LCC models and mission effects/kill-chain costs. The Air Force regularly uses LCCs to determine and budget for the total cost of owning weapon systems from initial capitalization through recurring operation, maintenance, and repairs. LCC analysis considers a wide variety of cost elements, including infrastructure for all aspects of the weapon system enterprise, personnel associated with all aspects of owning a weapon system, equipment and spare parts cost, operations and maintenance costs, cost of training personnel within the weapon systems enterprise, and others. All of these factors are rolled up to compute a long-term cost associated with owning the weapon system.

In addition to considering LCCs (also known as *total ownership costs*), workshop participants noted the value of including the costs associated with using one combat weapon system platform versus another to achieve a combat effect. We refer to these as *mission effects costs*. There are relationships and dependencies across weapon system platforms that must operate together in order for a combat weapon system to deliver the combat effect required. Noncombat weapon system platforms operating together enable the delivery of the combat effect. For example, to use a fighter aircraft in combat from a forward deployed location, the unit must deploy along with a number of other units that provide base operating support at the forward location. Force deployments require strategic airlift and air refueling to move the units to the forward operating location. Once at the forward operating location, there are significant requirements for intelligence and reconnaissance assets to inform target selection and communications and information system infrastructure to command and control the combat forces as they deliver their combat effects.

The enabling weapon systems also have an LCC or cost of ownership associated with them. When considering different alternatives to achieve a desired effect, portions of the cost of the *enabling weapon systems* must be allocated to the mission effects chain cost associated with employing a particular *combat weapon system*. Life-cycle cost is a subcomponent of mission effects cost. For combat weapon systems (including kinetic and nonkinetic, manned and

unmanned), the LCC of the weapon system would be included in the kill-chain cost. For other systems described earlier as enablers, their LCC could be apportioned, however imperfectly, to the kill chain in a manner that reflects their role in enabling the effect. An approximate cost allocation would carry uncertainties, and indeed, could be handled explicitly by adding an additional uncertainty into the analysis that captured a range of possible “apportionments” of the LCCs of enablers.

The second set of metrics discussed are associated with operational success. Defining operational success could take a number of different paths. In one case, it might entail avoiding losses while achieving some minimal set of warfighting objectives. In another, it might be measured by how much damage is inflicted on the adversary’s ability to wage war, while minimizing collateral damage in the process. These are just two possibilities, however. Defining and setting the parameters for measuring operational success for an RDM analysis are crucial issues to address in any follow-up work and must be performed in close consultation with Air Force stakeholders.

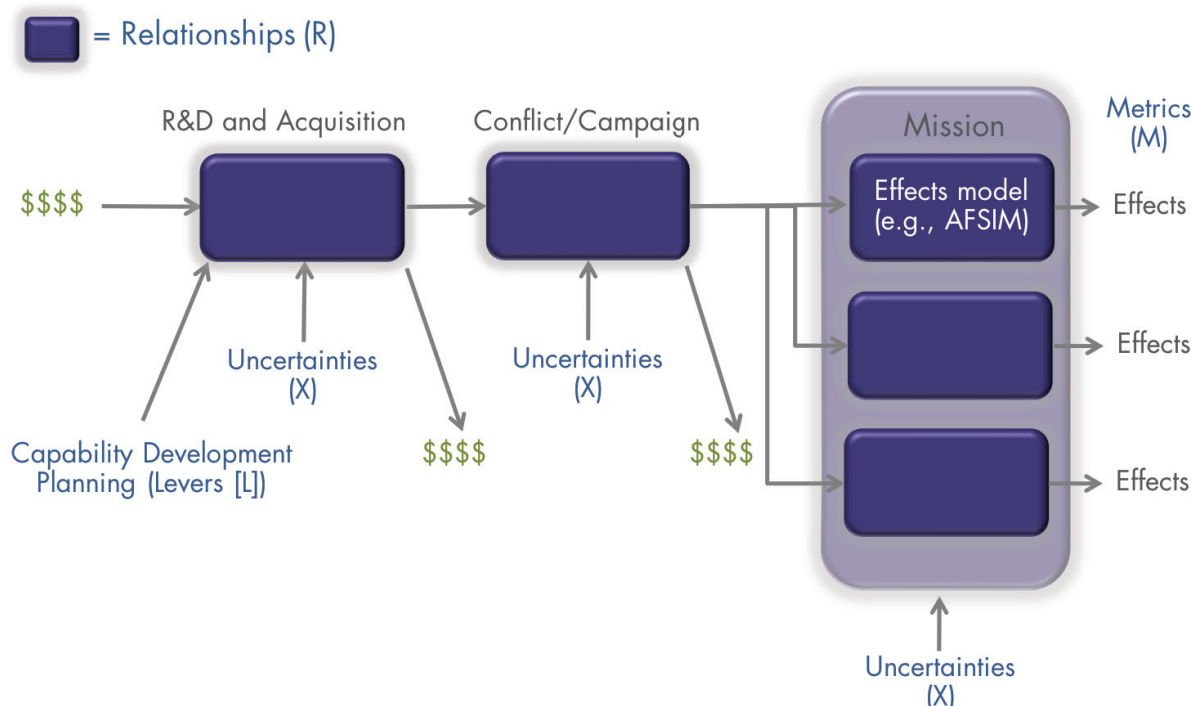
Workshop participants also highlighted that some quantifiable attribute of deterrence could be a third metric. *Deterrence* is the absence or avoidance of conflict. In the context of capability development and force structure mixes, deterrence could be difficult to model or represent quantitatively, but it is nevertheless an important goal for long-term Air Force investments and one that should be taken into account if possible.

A fourth class of metrics not raised in the workshop but tractable and relevant in a highly uncertain threat environment is *resilience*: the capacity of a particular capability to withstand a disruption or “kill” and default to an alternative means of delivering an effect. This could be measured as a separate quantitative output from the simulation models, or it could emerge from the RDM analysis itself when comparing the performance of different policy levers across a range of plausible futures.

Relationships

A quantitative analysis of CDP would likely utilize some integration of campaign, combat effects, acquisition, and cost models to take in various uncertainties and policy levers and estimate outcome metrics. Campaign-level models would be used to analyze how different future force structures could perform in varying future security environments. Combat effects models would be used to analyze performance of newly emergent technologies, CONOPs, or modifications of existing platforms or munitions. Cost and acquisition models would be used to estimate the cost of owning the force structure, the cost of using the force structure to deliver the combat effects required to defeat adversaries, and the timing and availability of aircraft, weapon systems, munitions, or other technological supports over time across a range of plausible futures. A notional modeling approach that came out of the workshop discussions is shown in Figure 5.1. The figure indicates where uncertainties and levers would be introduced, as well as where cost and effects metrics would be produced from the coupled system.

Figure 5.1. A Notional Integrated Modeling Approach for a Capability Development Planning Problem



Detailed integrated modeling would be a very tall order and not within reach in the near term. Having said that, there are a number of campaign-level models that could be used to inform a more qualitative approach to understanding the performance of different force structures and weapon system platforms. The most notable are STORM (Seymour, 2014) and THUNDER (Joint Aircraft Survivability Program, 2019b). An important factor in considering models is the degree to which they can differentiate the performance of one weapon system versus another in delivering the combat effects needed to succeed in a campaign. Effects-based models that were highlighted in the workshop include BRAWLER (Joint Aircraft Survivability Program, 2019a), which simulates air-to-air combat engagements, and SUPPRESSOR, which simulates air-to-ground combat effects (Douglas, 2000). Relatedly, existing or new models built on the AFSIM platform could be used to represent a wide range of combat effects in different environments. Workshop participants were not able to identify models that analyzed the effectiveness of nonkinetic weapons to achieve combat effects.

These models are complicated. In their current form, they are unwieldy for conducting many runs of plausible futures. Accordingly, their use in an RDM or other DMDU-based analysis might be limited to informing a qualitative analysis, such as simulating performance for a few different weapon systems against different target sets under a small number of futures. Similarly, qualitative output from various wargames, including those with scenarios based on current

threats and others focused on future capabilities and threats, could also be incorporated into a qualitative RDM or DMDU analysis.

Cost modeling, or at a minimum, cost data, would also be required for a capability development analysis. Existing LCC models or methods could be adapted to estimate the investment costs associated with a range of weapons platforms. Mission effects cost models would allow for a more informed comparison of weapon systems costs to assure campaign success. Simple cost models would be a practical first step to take in an RDM or other DMDU analysis.

In a quantitative analysis, the Air Force would need to use an integrated modeling platform to assess the relative cost and effectiveness of portfolios of levers across a range of possible futures. Each combination of a lever portfolio and a particular future (a unique combination of uncertainties, as described above) would be called a *case*. Results from all cases would be stored in a database that could then be queried by decisionmakers through statistical algorithms and data visualization software to gain insights into cost and effectiveness trade-offs across the portfolios and the robustness of portfolios across the range of possible futures. Practically speaking, a qualitative approach can be incrementally enhanced over time as individual modeling components are improved and validated over time.

Key Findings and Conclusions

The XLRM exercise revealed the layers of complexity embedded within CDP and highlighted the challenge of producing decision-quality analysis to support design and planning choices. CDP is a difficult problem. Challenges emerge from the outset, when the decision problem itself is being framed. Is the right question being asked? Is it analytically tractable? Do the levels of uncertainty and complexity justify the use of the analytical method chosen? In particular, while the performance measures may appear relatively straightforward in principle, data to inform those measures may not be accessible, and Air Force stakeholders may disagree on the best approach to measuring effectiveness or success. Similarly, coupling models or data sets to accurately capture the effect of adjusting levers remains a tall order. Workshop participants noted that while models at the appropriate level of abstraction may be difficult to come by, this type of enterprise-level modeling capability is an important need and one worthy of developing in support of CDP. In the meantime, qualitative approaches can at best be supplemented with gamed or modeled results where and when appropriate.

These technical limitations represent one type of implementation challenge. Another relates to the resistance that can be expected to arise within the Air Force, or any established organization of this size and complexity, to adopting these new and holistic approaches. RDM and similar methods represent a fundamental shift in problem-solving, from predict-then-act analysis to a vulnerability and risk management approach. The key output of this type of approach is not a single answer, but rather trade-off curves or other visualizations that compare

performance of alternative strategies or portfolios of options to the status quo in terms of metrics that reflect what is most important to the Air Force. Ultimately, RDM and other DMDU approaches help to highlight key decision-relevant scenarios and trade-offs, but Air Force decisionmakers themselves would still need to resolve these trade-offs and identify suitably robust plans or investments that satisfy relevant stakeholders.

Workshop participants found the RDM approach intellectually appealing, but noted the need for scoping the problem to a single cross-functional issue for the purposes of producing a timely and useful application. The time required to carry out a full RDM exercise is dependent on the availability of simulation models, if they are to be used at all, and associated data. If models and data are available, accessible, and ready to run, then the exercise and analysis could be completed within a few months. However, if the models are not fully developed or the data difficult to access for classification or other reasons, the process could take much longer if a quantitative approach were pursued.

This led to a discussion of the attractiveness of pursuing an application with SDPE and AFWIC teams that would combine an XLRM workshop as was conducted in this study with the qualitative method of ABP, described in Chapter 4. ABP would be less dependent on simulation modeling and instead would rely on a structured series of in-depth discussions about the effects that could be expected from any number of alternative investment strategies under a range of selected scenarios. An ABP exercise would also include the articulation of hedging and shaping strategies to reduce risks under each of the scenarios. Another output of ABP would be performance metrics or metrics associated with the external threat or technology environment that serve as “signposts” that assumptions underlying the capability development plan might no longer hold true. Signposts would then trigger an adaptive strategy to change course and further mitigate the newly emergent vulnerabilities.

In the final chapter, we discuss the attributes of a well-posed test application and the steps that would need to be taken to execute a test of DMDU methods on a real problem of consequence to AFWIC within a time frame of less than a year.

6. Recommendations and Next Steps

With the establishment of AFWIC in October 2017, SDPE's role in CDP has been evolving. As had been the case before AFWIC, SDPE is tasked with providing analytical support to the CDC and CDWG, as originally conceived in the CSAF's memo establishing new capability development processes within the Air Force (James and Welsh, 2016). However, as AFWIC's staffing and processes have begun to take shape, SDPE's role has been sharpened to provide key modeling, simulation, and other analytical needs to support AFWIC's development of capability development guidance. Notwithstanding the organizational shifts, the same analytical needs remain to support CDP, namely how to

- choose among alternative portfolios of enhanced or new capabilities and R&D
- design ECs to reduce uncertainties and risks.

Following an assessment of the current Air Force analytical approach to CDP, we describe alternative approaches to resource allocation decisionmaking under uncertainty, tested and documented in other contexts, that are available to SDPE to meet AFWIC's analytical needs for modeling, simulation, and ECs. The PAF team then conducted a workshop with RAND analysts with expertise in the Air Force, strategy and planning processes, and decision analysis to walk through the first step of decision-framing that precedes each of the DMDU methods. The workshop served to sharpen the team's understanding of the opportunities and challenges of implementing a new approach to decision support for CDP and to help chart a path toward an application that could both meet AFWIC's near-term needs and demonstrate the advantages and disadvantages of the DMDU method in the Air Force context.

As a first step, we recommend that SDPE, in consultation with AFWIC, choose a timely and relevant investment/divestment decision problem. Using RDM or another appropriate DMDU method, SDPE would set out to demonstrate the robustness of a number of alternative investment portfolios encompassing a range of emerging technologies, such as quantum computing, artificial intelligence, hypersonics, and directed energy. The analysis would consider performance under a wide range of future conditions and visualize trade-offs among these alternatives across the performance metrics relevant to Air Force decisionmakers. For example, a tractable piece of one of the following illustrative problems could be chosen that would draw on an existing and well-understood functional or mission-level model.

- **Succeeding in combat against increasing capable IADS:** Compare and contrast alternative means to deliver effects and achieve success against these threats, including (but not limited to) the most effective uses of manned and unmanned fighters, bombers, and other aircraft; terrestrial and space-based intelligence surveillance and

reconnaissance capabilities; active and passive electronic warfare capabilities including those of other military departments; and cyber capabilities

- **Providing robust Close Air Support (CAS):** Compare and contrast alternative means to provide CAS across the spectrum of combat, including manned and unmanned systems (carrying sensors and/or weapons) in the context of the full set of applicable Joint Force capabilities
- **Maintaining robust capabilities to conduct long-range strike:** Compare and contrast alternative means to locate and attack targets from long range including (but not limited to) manned and unmanned platforms and sensors, kinetic and directed energy weapons, and space- and terrestrially based systems. This could intersect with analysis of the means to counter IADS, and should be conducted in the context of the capabilities of the Joint Force
- **Integrating CSRT across the Air Force and Joint Force:** Compare and contrast alternative “system-of-system” means to conduct CSRT including (but not limited to) using tankers, cargo aircraft, bombers, fighters, commercial aircraft, oceans surveillance aircraft, and unmanned aircraft equipped to perform both their primary missions and CSRT

To be workable, a test application will need to be amenable to analysis even if done qualitatively. Among the criteria that would be desirable are the following:

- basic access to data that could be used to establish performance under a baseline or status quo CONOPs and existing capabilities
- classification level that could be managed to enable serious analysis and reveal key developments underway but not overly restrict the necessary audience of key analysts and decisionmakers
- AFWIC, SDPE, MAJCOM, and Joint Force stakeholders who are willing to engage in an iterative process in developing the XLRM matrix, including the identification of performance metrics, key uncertainties, modeling tools, and investment/divestment strategies (levers)
- problem-scoping that could accommodate a qualitative analysis within 8–12 months of initiation, including all relevant data collection, modeling, analysis, visualization, and interactive review of and response to results.

At this time, practical and conceptual constraints on suitable simulation models to support CDP likely preclude a fully quantitative application of RDM in the near term. However, SDPE could be a leader within the Air Force for building an integrated modeling platform that over time could support the CDP enterprise. In the meantime, validated models have an important role to play in informing qualitative analysis of uncertainties shaping CDP.

Furthermore, gathering the expertise to inform how CONOPs may need to change in response to a wide range of possible future conditions is a difficult task. SDPE has not been tasked with the challenge of addressing the alternative concepts for possible future conditions. The assumption, embedded in the CDP charter (James and Welsh, 2016), was that SDPE would receive direction from the AFSEA, AFFOC, SMP, and Core Function Master Plans. However, with the formation of AFWIC, AFSEA and the other related documents have largely faded away, and AFWIC has instead been tasked with responsibility for formulating alternative CONOPs. SDPE could support AFWIC by relying on lower-resolution models that may provide a practical path forward for representing uncertainties and providing insights about potential performance of new capabilities across a tractable number of scenarios.

Cultivating a close, collaborative, trust-based relationship with the AFWIC team will be essential to SDPE's effectiveness as a leader in decision support to the Air Force DP enterprise. Thus, AFWIC's engagement will be needed at each step of the application process.

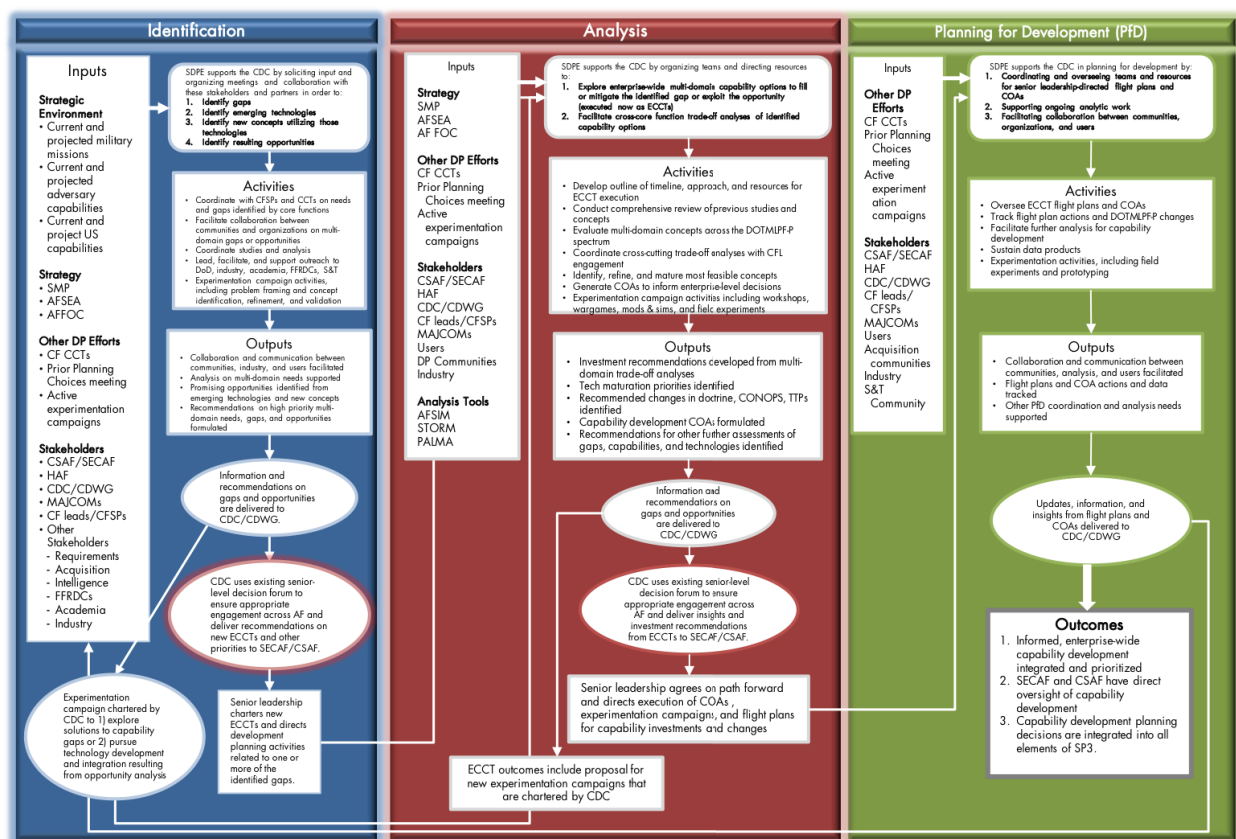
Appendix: Background Information on Capability Development Planning and Strategy, Planning, and Programming Process

This appendix briefly describes Air Force processes that predate the establishment of AFWIC but existed at the time this project commenced. For archival purposes, we include this background information for our readers.

Logic Model for Capability Development Planning (Pre–Air Force Warfighting Integration Capability)

Based on interviews and review of documents describing the functions, activities, and relationships of SDPE prior to the establishment of AFWIC (James and Welsh, 2016; USAF, 2016b; USAF, 2017), the PAF team developed a logic model of SDPE processes for CDP (Greenfield, Williams, and Eiseman, 2006).

Figure A.1. Capability Development Planning Logic Model



Background on SP3

Defining a clear strategy is the first step in planning and programming processes within the Air Force.¹ There are a number of products that result from SP3, each one of which guides subsequent steps in the process. CDP is contending with competing alternatives about how, given a mix of capabilities, the required military effects can be achieved in the context of a particular CONOPs concept of operations. The AFSEA and AFFOC together set the context for the Air Force of the future, with the AFSEA addressing future threats and the AFFOC addressing how the Air Force will operate in light of those threats. The SMP subsequently sets forth the actions needed to move the Air Force toward being the future force it envisions. Taken together, this triad of documents establishes the future threat scenarios the Air Force will operate in, a vision for the composition of the future force, and a broad strategy for how to achieve change.

In 2016 and 2017, AF/A5/8 used these documents to create and issue Strategic Planning Guidance to direct and coordinate strategic planning. A Ten-Year Integrated Plan was jointly created by Headquarters, Air Force (HAF), and the MAJCOMs to inform the 30-year RAP.² The long-range resource planning decisions for capability development contained in these resourcing plans (specific “planning choices”) were finalized in the annual Planning Choices event, with final input from CSAF and SECAF. To date, the Planning Choices event has been a meeting attended by the MAJCOM commanders and the three-star-level functional leads for the HAF A-staff (e.g., AF/A1, AF/A2, and so on). It is chaired by the SECAF and CSAF. This group of Air Force leaders makes the final investment decisions tied to the prior planning documents and approves the finalized Ten-Year Integrated Plan and 30-year RAP.

Following this event, the Director of Plans, AF/A8X, releases Plan-to-Program Guidance (PPG). This document links the strategy and planning phases of the SP3 and details the impacts of the Planning Choices event decisions and direction for the creation of the POM. The POM is informed by the Plan-to-Program Guidance and intended to guide near-term resourcing and acquisition decisions (USAF, 2016b).

¹ *Strategy* and *strategic* are common—and critical—terms used in the context of CDP. The common dictionary definition of strategy is “the science and art of military command exercised to meet the enemy in combat under advantageous conditions.” More specifically, strategy is defined in the U.S. military as “a prudent idea or set of ideas for employing the instruments of national power in a synchronized and integrated fashion to achieve theater, national, and/or multinational objectives” (DoD, 2017, p. GL-15).

² According to Air Force Policy Directive 90-11, the Ten-Year Integrated Plan is developed by AF/A8X in the first phase of the planning cycle and is intended to aid in achieving interim goals aligned with SMP objectives and the AFFOC and to inform the 30-year RAP. It guides resourcing decisions over several planning cycles to maintain the path toward long-term Air Force goals. The RAP provides a strategy-driven 30-year force structure and fiscal plan that informs the PPG.

References

- Air Force Materiel Command, “Development Planning (D64P) Guide,” Wright-Patterson Air Force Base, OH: Air Force Materiel Command Directorate of Intelligence and Requirements, 2010.
- Bankes, Steven C., “Exploratory Modeling for Policy Analysis,” *Operations Research*, Vol. 41, No.3, 1993, pp. 435–449.
- Ben-Haim, Yakov, *Info-Gap Decision Theory: Decisions Under Severe Uncertainty*, 2nd ed., New York: Academic Press, 2006.
- Ben-Haim, Yakov, and Maria Demertzis, “Decision Making in Times of Uncertainty: An Info-Gap Perspective,” Working Paper No. 487, Amsterdam, The Netherlands: De Nederlandsche Bank NV, November 2015.
- Chermack, T., S. Lynham, and W. Ruona, “A Review of Scenario Planning Literature,” *Futures Research Quarterly*, Vol. 17, No. 2, 2001, pp. 7–31. As of May 17, 2019:
http://www.thomaschermack.com/Thomas_Chermack_-_Scenario_Planning/Research_files/ReviewofSP.PDF
- Chow, Brian G., “Portfolio Optimization by Means of Multiple Tandem Certainty-Uncertainty Searches: A Technical Description,” Santa Monica, Calif.: RAND Corporation, 2013. As of May 17, 2019:
https://www.rand.org/pubs/research_reports/RR270.html
- Clive, Peter D., Jeffrey A. Johnson, Michael J. Moss, James M. Zeh, Brian M. Birkmire, and Douglas D. Hodson, “Advanced Framework for Simulation, Integration and Modeling (AFSIM),” International Conference on Scientific Computing, Case Number: 88ABW-2015-2258, 2015, pp. 73–77. As of October 28, 2018:
<http://worldcomp-proceedings.com/proc/p2015/CSC7058.pdf>
- Danzig, R., *Driving in the Dark: Ten Propositions About Prediction and National Security*, Washington, D.C.: Center for a New American Security, October 2011.
- Davis, Paul K., *Analytic Architecture for Capabilities-Based Planning, Mission-System Analysis, and Transformation*, Santa Monica, Calif.: RAND Corporation, MR-1513-OSD, 2002. As of March 16, 2019:
https://www.rand.org/pubs/monograph_reports/MR1513.html

- , “Uncertainty-Sensitive Planning,” in *New Challenges, New Tools for Defense Decisionmaking*, edited by Stuart Johnson, Martin Libicki, and Gregory Treverton, Santa Monica, Calif.: RAND Corporation, MR-1576-RC, 2003, pp. 131–155. As of March 16, 2019:
https://www.rand.org/pubs/monograph_reports/MR1576.html
- , *Lessons from RAND’s Work on Planning Under Uncertainty for National Security*, Santa Monica, Calif.: RAND Corporation, TR-1429-OSD, 2012. As of March 16, 2019:
https://www.rand.org/pubs/technical_reports/TR1249.html
- , *Analysis to Inform Defense Planning Despite Austerity*, Santa Monica, Calif.: RAND Corporation, RR-482-OSD, 2014. As of March 16, 2019:
https://www.rand.org/pubs/research_reports/RR482.html
- , *Capabilities for Joint Analysis in the Department of Defense: Rethinking Support for Strategic Analysis*, Santa Monica, Calif.: RAND Corporation, RR-1469-OSD, 2016. As of March 16, 2019:
https://www.rand.org/pubs/research_reports/RR1469.html
- , RAND QA memorandum from David Orletsky, RAND PAF Quality Assurance Manager, July 2, 2018.
- Davis, Paul K., ed., *New Challenges in Defense Planning: Rethinking How Much Is Enough*, Santa Monica, Calif.: RAND Corporation, MR-400-RC, 1994. As of March 16, 2019:
https://www.rand.org/pubs/monograph_reports/MR400.html
- Davis, Paul K., Steven C. Bankes, and Michael Egner, *Enhancing Strategic Planning with Massive Scenario Generation: Theory and Experiments*, Santa Monica, Calif.: RAND Corporation, TR-392, 2007. As of March 16, 2019:
https://www.rand.org/pubs/technical_reports/TR392.html
- Davis, Paul K., and Paul Dreyer, *RAND’s Portfolio Analysis Tool (PAT): Theory, Methods, and Reference Manual*, Santa Monica, Calif.: RAND Corporation, TR-756-OSD, 2009. As of March 16, 2019:
https://www.rand.org/pubs/technical_reports/TR756.html
- Davis, Paul K., and James P. Kahan, *Theory and Methods for Supporting High Level Military Decisionmaking*, Santa Monica, Calif.: RAND Corporation, TR-422-AF, 2007. As of March 16, 2019:
https://www.rand.org/pubs/technical_reports/TR422.html
- Davis, Paul K., Stuart E. Johnson, Duncan Long, and David C. Gompert, *Developing Resource-Informed Strategic Assessments and Recommendations*, Santa Monica, Calif.: RAND Corporation, MG-703-JS, 2008. As of March 16, 2019:
<https://www.rand.org/pubs/monographs/MG703.html>

- Davis, Paul K., Richard Kugler, and Richard Hillestad, *Strategic Issues and Options for the Quadrennial Defense Review*, Santa Monica, Calif.: RAND Corporation, DB-201-OSD, 1997. As of March 16, 2019:
https://www.rand.org/pubs/documented_briefings/DB201.html
- Davis, Paul K., Jimmie McEver, and Barry Wilson, *Measuring Interdiction Capabilities in the Presence of Anti-Access Strategies: Exploratory Analysis to Inform Adaptive Strategies for the Persian Gulf*, Santa Monica, Calif.: RAND Corporation, MR-1471-AF, 2002. As of March 16, 2019:
https://www.rand.org/pubs/monograph_reports/MR1471.html
- Davis, Paul K., Russell D. Shaver, and Justin Beck, *Portfolio-Analysis Methods for Assessing Capability Options*, Santa Monica, Calif.: RAND Corporation, MG-662-OSD, 2008. As of March 16, 2019:
<https://www.rand.org/pubs/monographs/MG662.html>
- Dewar, James A., *Assumption-Based Planning: A Tool for Reducing Avoidable Surprises*, Santa Monica, Calif., RAND Corporation, CB-399, 2002. As of March 16, 2019:
http://www.rand.org/pubs/commercial_books/CB399.html
- Dewar, James A., Carl H. Builder, William M. Hix, and Morlie Levin, *Assumption-Based Planning: A Planning Tool for Very Uncertain Times*, Santa Monica, Calif.: RAND Corporation, MR-114-A, 1993. As of March 16, 2019:
https://www.rand.org/pubs/monograph_reports/MR114.html
- DoD—See U.S. Department of Defense.
- Douglas, Gregory L., *A Case Study on Model Integration, Using Suppressor*. Interservice/Industry Training, Simulation and Education Conference (I/ITSEC) 2000, paper number MS-017, 2000, p. 76. As of May 9, 2019:
<https://apps.dtic.mil/dtic/tr/fulltext/u2/a531699.pdf>
- Ehrgott, Matthias, “Multiobjective Optimization,” *AI Magazine*, Vol. 29, No. 4, 2008. As of March 16, 2019:
<https://doi.org/10.1609/aimag.v29i4.2198>
- Gallagher, Mark A., “Air Force Analytics for Decision Support,” *Journal of Cyber Security and Information Systems*, Special Edition, “Modeling & Simulation,” Vol. 3, No. 3, posted February 9, 2016. As of May 13, 2019:
<https://www.csiac.org/journal-article/air-force-analytics-for-decision-support/>
- , “The Air Force Comprehensive Core Capability Risk Assessment Framework,” Draft provided by M. A. Gallather (AF/A9) to RAND, October 6, 2017.

- Gallagher, Mark A., David J. Caswell, Brian Hanlon, and Justin M. Hill, “Rethinking the Hierarchy of Models and Simulations for Conflicts,” *Military Operations Research*, Vol. 19, No. 4, 2014, pp. 15–24. As of March 16, 2019:
doi:10.5711/1082598319415
- Greenfield, Victoria, Valerie L. Williams, and Elisa Eiseman, “Using Logic Models for Strategic Planning and Evaluation: Application to the National Center for Injury Prevention and Control,” Santa Monica, Calif.: RAND Corporation, TR-370-NCIPC, 2006. As of March 16, 2019:
https://www.rand.org/pubs/technical_reports/TR370.html
- Groves, David G., Jordan R. Fischbach, Evan Bloom, Debra Knopman, and Ryan Keefe, *Adapting to a Changing Colorado River: Making Future Water Deliveries More Reliable Through Robust Management Strategies*, Santa Monica, Calif.: RAND Corporation, RR-242-BOR, 2013. As of March 16, 2019:
https://www.rand.org/pubs/research_reports/RR242.html
- Groves, David G., and Robert J. Lempert, “A New Analytic Method for Finding Policy-Relevant Scenarios,” *Global Environmental Change Part A: Human & Policy Dimensions*, Vol. 17, No. 1, 2007, pp. 73–85. As of March 16, 2019:
doi:10.1016/j.gloenvcha.2006.11.006
- Groves, David G., Christopher Sharon, and Debra Knopman, *Planning Tool to Support Louisiana’s Decisionmaking on Coastal Protection and Restoration: Technical Description*, Santa Monica, Calif.: RAND Corporation, TR-1266-CPRA, 2012. As of March 16, 2019:
https://www.rand.org/pubs/technical_reports/TR1266.html
- Haasnoot, M., J. H. Kwakkel, W. E. Walker, and J. ter Maat, “Dynamic Adaptive Policy Pathways: A Method for Crafting Robust Decisions for a Deeply Uncertain World,” *Global Environmental Change*, Vol. 23, No. 2, 2013, pp. 485–498.
- Hencke, Richard,. “Experimentation Campaigns and Capability Development,” Presentation provided to RAND, Wright-Patterson Air Force Base, OH: Strategic Development Planning and Experimentation Office Experimentation Division, 2017.
- Hillestad, Richard, and Paul K. Davis, *Resource Allocation for the New Defense Strategy: The Dynarank Decision Support System*, Santa Monica, Calif.: RAND Corporation, MR-996-OSD, 1998. As of March 16, 2019:
https://www.rand.org/pubs/monograph_reports/MR996.html
- James, Deborah Lee, and Mark A. Welsh, “Charter for Air Force Capability Development,” Washington, D.C.: U.S. Air Force, 2016.

- Joint Aircraft Survivability Program, “BRAWLER: Tactical Air Combat Simulation,” 2019a. As of May 9, 2019:
<http://jasp-online.org/model-simulations/brawler/>
- , “THUNDER, Two-Sided Theater Campaign Simulation,” 2019b. As of May 9, 2019:
<http://jasp-online.org/model-simulations/thunder/>
- Joint Chiefs of Staff, “Joint Risk Analysis,” *Chairman of the Joint Chiefs of Staff Manual*, 3105.01, October 14, 2016. As of October 8, 2018:
<http://www.jcs.mil/Portals/36/Documents/Library/Manuals/CJCSM%203105.01%C2%A0.pdf?ver=2017-02-15-105309-907>
- Kahn, Herman, *Thinking About the Unthinkable*, New York: Horizon Press, 1965.
- Kasprzyk, Joseph R., Shanthi Nataraj, Patrick M. Reed, and Robert J. Lempert, “Many Objective Robust Decision Making for Complex Environmental Systems Undergoing Change,” *Environmental Modelling & Software*, Vol. 42, April 2013, pp. 55–71. As of March 16, 2019:
<http://dx.doi.org/10.1016/j.envsoft.2012.12.007>
- Kent, Glenn A., Randall J. DeValk, and David E. Thaler, *A Calculus of First-Strike Stability (A Criterion for Evaluating Strategic Forces)*, Santa Monica, Calif.: RAND Corporation, N-2526-AF, 1988. As of March 16, 2019:
<https://www.rand.org/pubs/notes/N2526.html>
- Knight, Frank H., *Risk, Uncertainty, and Profit*, Hart, Schaffner, and Marx Prize Essays, no. 31, Boston: Houghton Mifflin, 1921.
- Kwadijk, Jaap C. J., Marjolijn Haasnoot, Jan P. M. Mulder, Marco M. C. Hoogvliet, Ad B. M. Jeuken, Rob A. A. van der Krogt, Niels G. C. van Oostrom, Harry A. Schelfhout, Emiel H. van Velzen, and Harold van Waveren, “Using Adaptation Tipping Points to Prepare for Climate Change and Sea Level Rise: A Case Study in the Netherlands,” *Wiley Interdisciplinary Reviews: Climate Change*, Vol. 1, No. 5, 2010, pp. 729–740.
- Lempert, R. J., S. W. Popper, and S. C. Bankes, *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis*. Santa Monica, Calif.: RAND Corporation, MR-1626-RPC, 2003. As of March 16, 2019:
https://www.rand.org/pubs/monograph_reports/MR1626.html
- Lempert, Robert J., Steven W. Popper, David G. Groves, Nidhi Kalra, Jordan R. Fischbach, Steven C. Bankes, Benjamin P. Brynt, et al., *Making Good Decisions Without Predictions*, Santa Monica, Calif.: RAND Corporation, RB-9701, 2013. As of March 16, 2019:
http://www.rand.org/pubs/research_briefs/RB9701/index1.html

- Lempert, Robert J., Michael E. Schlesinger, and Steven C. Bankes, “When We Don’t Know the Costs or the Benefits: Adaptive Strategies for Abating Climate Change,” *Climatic Change*, Vol. 33, 1996, pp. 235–274.
- Lempert, Robert J., Horacio R. Trujillo, David Aaron, James A. Dewar, Sandra H. Berry, and Steven W. Popper, *Comparing Alternative U.S. Counterterrorism Strategies: Can Assumption-Based Planning Help Elevate the Debate?* Santa Monica, Calif.: RAND Corporation, DB-548-RC, 2008. As of March 16, 2019:
https://www.rand.org/pubs/documented_briefings/DB548.html
- Lempert, Robert J., Drake Warren, Ryan Henry, Robert W. Button, Jonathan Klenk, and Katheryn Giglio, *Defense Resource Planning Under Uncertainty: An Application of Robust Decision Making to Munitions Mix Planning*, Santa Monica, Calif.: RAND Corporation, RR-1112-OSD, 2016. As of March 16, 2019:
https://www.rand.org/pubs/research_reports/RR1112.html
- Magee, Christopher, and Olivier de Weck, “Complex System Classification,” International Council on Systems Engineering (INCOSE), July 24, 2004. As of March 16, 2019:
<http://hdl.handle.net/1721.1/6753>
- Mankins, John C., “Technology Readiness Assessments: A Retrospective,” *Acta Astronautica*, Vol. 65, April 2009, pp. 1216–1223. As of November 15, 2018:
<http://www.onethesis.com/wp-content/uploads/2016/11/1-s2.0-S0094576509002008-main.pdf>
- Metropolis, N., and S. Ulam, “The Monte Carlo Method,” *Journal of the American Statistical Association*, Vol. 44, 1949, pp. 335–341.
- Morgan, M. Granger, and Max Henrion, *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, New York: Cambridge University Press, 1992.
- Mosher, David E., “Prospects of DOD’s Defense Budget over the Next Decade,” Congressional Budget Office, Presentation by David E. Mosher, Assistant Director for CBO’s National Security Division, at the Professional Services Council’s 2018 Federal Strategic Planning Forum, February 5, 2018. As of May 11, 2018:
<https://www.cbo.gov/publication/53542>
- NASEM—See National Academies of Sciences, Engineering, and Medicine.
- Nason, Rick, *It’s Not Complicated: The Art and Science of Complexity in Business*, Toronto: University of Toronto Press. 2017.
- National Academies of Sciences, Engineering, and Medicine, *The Role of Experimentation Campaigns in the Air Force Innovation Life Cycle*. Washington, D.C.: National Academies Press. 2016.

- National Defense Panel, *Transforming Defense: National Security in the 21st Century*, Washington, D.C.: Department of Defense, 1997.
- National Research Council, *Development Planning: A Strategic Approach to Future Air Force Capabilities*. Washington, D.C.: National Academies Press, 2014.
- NRC—See National Research Council.
- Ochmanek, David A., Ted Harshberger, David E. Thaler, and Glenn A. Kent, *To Find, and Not to Yield: How Advances in Information and Firepower Can Transform Theater Warfare*, Santa Monica, Calif.: RAND Corporation, MR-958-AF, 1998. As of March 16, 2019:
https://www.rand.org/pubs/monograph_reports/MR958.html
- Rumsfeld, Donald, *Report of the Quadrennial Defense Review*, Washington, D.C.: Department of Defense, 2001.
- , “Transforming the Military,” *Foreign Affairs*, Vol. 3, May/June 2002. As of June 4, 2019:
<https://www.foreignaffairs.com/articles/2002-05-01/transforming-military>
- Schoemaker, Paul J. H., “Scenario Planning: A Tool for Strategic Thinking,” *Sloan Management Review*, Winter 1995, pp. 25–40.
- Schwartz, Peter, *The Art of the Long View: Planning for the Future in an Uncertain World*, New York: Currency Doubleday, 1991.
- Seymour, Christian, “Capturing the Full Potential of the Synthetic Theater Operations Research Model (STORM),” Ph.D. dissertation, Naval Post-Graduate School, 2014.
- USAF—See U.S. Air Force.
- U.S. Air Force, *Strategic Master Plan*, May 1, 2015.
- , “Air Force Communications Waypoints, Winter 2016,” 2016a. As of May 14, 2019:
http://www.airuniversity.af.mil/Portals/10/CMSA/documents/Required_Reading/USAF%20Communication%20Waypoint%20-%20Winter%202016.pdf
- , Guidance Memorandum 2016-90-1101, *Air Force Strategic Planning Process*, October 3, 2016b. As of May 14, 2019:
<https://afacpo.com/AQDocs/afgm2016-90-1101.pdf>
- , “Air Superiority 2030 Enterprise Capability Collaboration Team Flight Plan,” 2016c. As of May 14, 2019:
<https://www.af.mil/Portals/1/documents/airpower/Air%20Superiority%202030%20Flight%20Plan.pdf>

- , *United States Air Force Strategic Environment Assessment 2016–2046*, Washington, D.C.: Directorate of Strategy, Concepts, and Assessments, Deputy Chief of Staff for Strategic Plans and Requirements, Headquarters United States Air Force, 2016d.
- , Memorandum from the Secretary of the Air Force and the Chief of Staff of the Air Force, “Establishment of an Air Force Warfighting Integration Capability,” Washington, D.C.: Offices of the Secretary of the Air Force and the Chief of Staff of the Air Force, October 2017.
- , “Air Force Warfighting Integration Capability (AFWIC) Concept of Operations (CONOPS),” Washington, D.C.: Air Force Warfighting Integration Capability, March 2018.
- U.S. Department of Defense, *Technology Readiness Assessment (TRA) Deskbook*, Prepared by the Director, Research Directorate (DRD), Office of the Director, Defense Research and Engineering (DDR&E), July 2009. As of November 15, 2018:
https://www.skatelescope.org/public/2011-11-18_WBS-SOW_Development_Reference_Documents/DoD_TRA_July_2009_Read_Version.pdf
- , *Joint Operations*, Joint Publication 3-0, January 17, 2017. As of May 14, 2019:
https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_0ch1.pdf?ver=2018-11-27-160457-910
- , *National Defense Strategy of the United States of America*, 2018. As of May 14, 2019:
<https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf>
- The White House, *National Security Strategy of the United States*, Washington, D.C.: December 2017. As of May 14, 2019:
<https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf>

In view of uncertainties about the future threat environment, trajectories of technological development, and shifting budgeting priorities, RAND Project AIR FORCE examined analytical methods that would best guide the recently established Air Force Warfighting Integration Capability in capability development planning (CDP), as well as concept development and future force design. In their review, researchers found that specific methods of decisionmaking under deep uncertainty (DMDU) can provide the most suitable means for arriving at solutions that are flexible, adaptable, and robust and guiding investment pathways and modernization efforts.

The method highlighted, Robust Decisionmaking, rests on a simple concept. Rather than using models and data to assess policies under a single set of assumptions, RDM runs models over hundreds to thousands of different sets of assumptions about the problem space with the aim of understanding how plans perform under many plausible conditions. Each of the four steps of RDM—decision-framing, case generation, vulnerability assessment and scenario discovery, and trade-off analysis—feeds into the next, providing stakeholders and decisionmakers with a more informed tradespace. By exposing vulnerabilities of different options under different scenarios, RDM can enable stakeholders to engage in a rich dialogue about which risks or vulnerabilities are acceptable, as well as to review assumptions made in framing the problem and make adjustments as needed.



PROJECT AIR FORCE

www.rand.org

\$30.00

ISBN-10 1-9774-0308-5
ISBN-13 978-1-9774-0308-7

