This report describes RAND's Multi-Purpose Assessment of Force Flow (MPAFF) tool for conducting quick, time-phased analysis of force sufficiency under a variety of assumptions on force generation policies, readiness policies, and force employment policies for the U.S. Army. This tool is part of a larger analytic approach developed by RAND to assess the risks and costs of proposed changes in Army force structures and associated readiness and force generation policies in a more rapid way than traditional assessment approaches, while preserving enough fidelity to continue to support Army decisionmakers. The MPAFF tool comes in two variants. The original MPAFF tool is designed to provide quick-turn analysis to support Army force and budget planning. The MPAFF-J variant provides the same analysis in a package that supports running thousands (even millions) of cases rapidly to enable sensitivity analysis and exploration of the robustness of potential policy options. The approach embraced by both variants uses input data generally available to Army planners and makes use of existing models and parameters available to the Army and RAND. The information provided by this analytic approach provides insight on the capacity and capability of an Army force structure to meet various strategic demands, as well as the effects of broad changes to policies related to force size, capabilities mix, force generation and readiness, reserve component usage, and beliefs about future threats.

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Preface

This report documents research and analysis conducted as part of a project entitled *Strategic Framework for Army Capabilities and Capacity [FY15–FY19]*, sponsored by the Director of Program Analysis and Evaluation, Office of the Deputy Chief of Staff, G-8, U.S. Army. The purpose of the project was to help the Army refine a repeatable, defendable approach to identifying strategic requirements for Army forces and support high-level decisions regarding force structure, readiness, modernization, and personnel to help the Army inform defense strategy and program development.

This research was conducted within the RAND Arroyo Center's Strategy, Doctrine, and Resources Program. RAND Arroyo Center, part of the RAND Corporation, is a federally funded research and development center (FFRDC) sponsored by the United States Army.

RAND operates under a "Federal-Wide Assurance" (FWA00003425) and complies with the *Code of Federal Regulations for the Protection of Human Subjects Under United States Law* (45 CFR 46), also known as "the Common Rule," as well as with the implementation guidance set forth in DoD Instruction 3216.02. As applicable, this compliance includes reviews and approvals by RAND's Institutional Review Board (the Human Subjects Protection Committee) and by the U.S. Army. The views of sources utilized in this study are solely their own and do not represent the official policy or position of DoD or the U.S. Government.

Contents

Figures

Tables

Summary

Fiscal pressures are causing the U.S. Army to explore a variety of force structure options and possible changes to readiness policies and force generation mechanisms. At the same time, the potential strategic demands on the Army are changing rapidly: While U.S. forces are drawing down in Afghanistan, the United States is facing both old and new threats in the Middle East, rebalancing in the Western Pacific, and a rising threat to the North Atlantic Treaty Organization (NATO) in eastern Europe. This situation puts Army leaders in a difficult situation. To argue effectively for resources, they must be able to articulate the risks that accompany fiscal constraints. At the same time, they must design the best Army possible given the fiscal constraints imposed.

To do this, the Army needs an analytic process that enables it to rapidly assess risk and budget implications across a variety of proposed force structures, readiness policies, and force generation policies. Traditionally, the Army does this using the Total Army Analysis and Program Objective Memorandum (POM) processes. While these processes do produce authoritative answers, they take too long and are too complex to use for exploratory examinations. To support the exploration and intermediate decisionmaking needed to develop the Army POM, Army G-8/Program Analysis and Evaluation desires a rapid, responsive process that produces approximate answers and enables analysts to present the pros and cons of force structure and policy options to Army leadership.

To this end, Army leaders asked RAND to help them understand how such rapid assessments could be performed. RAND reviewed existing tools and methods and developed an overall approach that provides the desired assessment information. This report introduces RAND's Multi-Purpose Assessment of Force Flow (MPAFF), a quick-turn force sufficiency assessment tool that is a key component of this overall methodology. The MPAFF model requires two key inputs, namely a time-phased estimate of the set of demands for Army forces in future conflicts and an actual or proposed force structure and associated policies on readiness, force generation, and force employment/management. From this, the tool produces a quantitative assessment of the capacity of the operational force structure and force generation to meet the demands. The MPAFF tool fills a gap in the ability to perform quantitative assessment of capacity relative to future demands under a particular set of force structure and force management policies

in a matter of seconds. Specifically MPAFF provides an advantage over other quick-turn tools available to Army leadership by being able to

- include assessment of the ability to meet demand over time, rather than just peak demands
- capture Army force structure at higher resolution than simply brigade combat teams (BCTs) and combat aviation brigades (e.g., at the battalion level or below)
- include various Army enablers and force elements that exist outside the BCT structure (e.g., air and missile defense units, Combat Service Support units)
- examine the effect of changes to the Army Force Generation process[1]
- explore alternative readiness models, such as steady-state or band-of-excellence readiness models
- evaluate the impact of changes to future force structure, including force size, capabilities mix, and access to the reserve component (RC) and Army National Guard
- cover a wider array of alternative futures in terms of future demand requirements.

Figure S.1 illustrates the basic flow of MPAFF's model logic. Beginning with inputs on supply, demand, and policies related to force generation and deployability, the model calculates the total demand for and supply of ready units in each period. Deployments are assigned and units set to reset depending on the policy rules previously set, resulting in an assessment of met versus unmet demands over time. From this information, the final output of the MPAFF model, decisionmakers can begin to assess operational impacts of shortages and the policy decisions they have chosen to model. In this work, we include illustrative outputs from sample model runs, highlighting some of the main strengths of the MPAFF model. MPAFF allows for the on-demand creation of automated output graphics and a detailed database for the construction of customized output graphics that capture capacity assessment results over time. These results can be used by Army leadership to help make high-level trade-off assessments about force size, mix, and force generation decisions.

The Excel-based MPAFF model is an interactive, human-in-the-loop tool that allows users to explore a single model run at a time. This is very useful for exploratory analysis, creation of visualizations, or an examination of the effects of a specific set of policy levers.[2] To facilitate additional types of analysis that require views across a large number of policy options and the interactions between them, RAND has developed a Java reimplementation of the Excel-based tool called MPAFF-J. The primary goal of this reimplementation is to facilitate the running of MPAFF for a large number of

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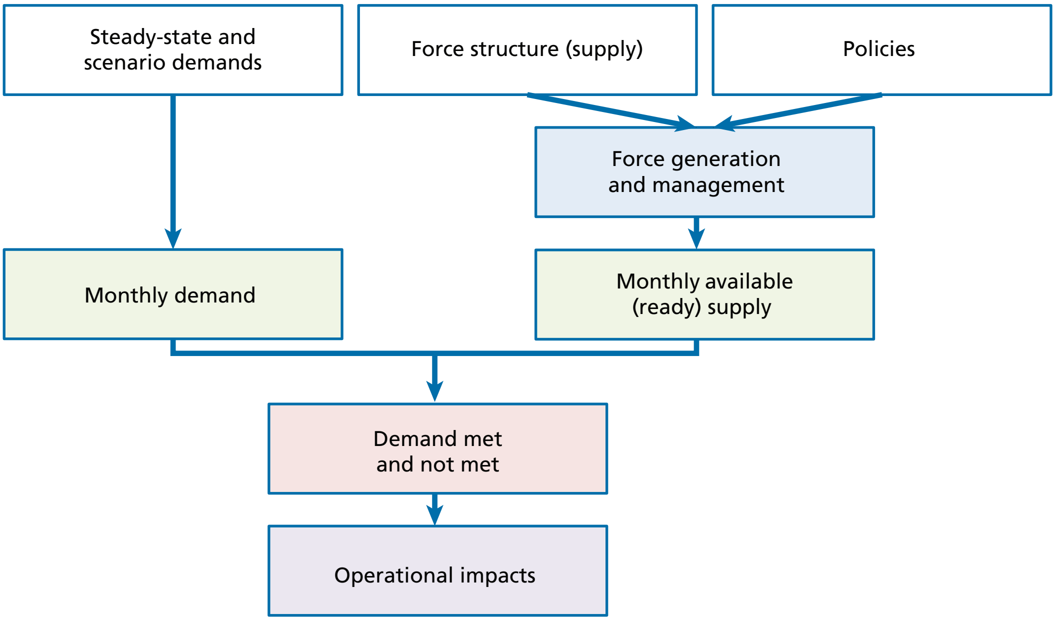
1 Headquarters, U.S. Department of the Army, *Army Force Generation*, Army Regulation 525–29, Washington, D.C., March 14, 2011a.

2 *Policy levers* are policy actions over which decisionmakers have at least some control, such as the size and constitution of the future force or the planned level of peacetime readiness.

Figure S.1
MPAFF Model Logic Outline



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combinations of the possible levers relating to supply (force structure), demand (scenarios), and force management (readiness models). A combinatorial set of runs that cover a large portion of the state space of these various levers can support an application of visualization and data analytics across multiple levers. We use this to help identify the key drivers of capacity issues. Our cross-lever data analytics approach helps identify potential strategies that are robust across a variety of possible futures, characterize the vulnerabilities of such strategies, and evaluate trade-offs among them. Using MPAFF-J, we can assess force sufficiency performance under a wide array of possible futures (scenarios) and identify which strategic decisions about force size, mix, and readiness have a large impact on the Army's ability to meet demand. Because MPAFF-J facilitates sensitivity analysis and enables statistical analysis about the robustness of policy options across a variety of unknowns, it can be used, for example, to explore how extreme force management actions must be to significantly improve the overall ability of the force to meet war demands. Similarly, the MPAFF-J tool can also be used, for example, to systematically explore the consequences of varying the separation between two wars to understand if such variations significantly affect the ability of a given Army force structure to meet war demands.

Abbreviations

ABCT	Armored Brigade Combat Team
AC	active component
AMD	air and missile defense
ARFORGEN	Army Force Generation
BCT	Brigade Combat Team
BOG	boots on ground
C1	more ready
C2	less ready
CAA	Center for Army Analysis
CAB	Combat Aviation Brigade
COCOM	Combatant Command
CSS	Combat Service Support
CTC	Combat Training Center
FCCM	Force Capacity and Cost Model
IBCT	Integrated BCT
IQR	interquartile range
ISC	integrated security construct
MCO	major combat operation
MPAFF	Multi-Period Assessment of Force Flow

MPAFF-J	MPAFF-Java
MSFD	multi-service force deployment document
OPLAN	operational plan
OSD	Office of the Secretary of Defense
POM	Program Objective Memorandum
RC	reserve component
RDM	Robust Decision Making
SBCT	Stryker BCT
SPADES	System for Periodically Apportioning Demands
SRC	Standard Requirements Code
SS	steady state
TAA	Total Army Analysis
TPFDL	time-phased force deployment list
TRAC	TRADOC Analysis Center
TRADOC	U.S. Army Training and Doctrine Command
USAFRICOM	U.S. Africa Command
USCENTCOM	U.S. Central Command
USEUCOM	U.S. European Command
USFORSCOM	U.S. Army Forces Command
USNORTHCOM	U.S. Northern Command
USPACOM	U.S. Pacific Command
USSOUTHCOM	U.S. Southern Command

CHAPTER ONE

Introduction

The U.S. Department of Defense devotes considerable time and effort to planning future military forces. The purpose of the force planning process is to ensure the availability of the right set of military capabilities to support the nation's priorities and goals in the expected environment in which those forces would operate.[1] The force planning process involves making decisions about how to allocate resources among competing priorities while incorporating *risk*—the potential for unexpected future outcomes relevant to national security. Incorporating risk involves both risk assessment and risk management. Risk assessment aims to understand the level of risk associated with different resourcing decisions, while risk management makes adjustments to resource decisions to minimize risk or focus risk in areas deemed acceptable by leaders. While there will never be sufficient resources to completely eliminate risk in an uncertain strategic environment, investments can be allocated among appropriate capabilities and capacities in various ways to mitigate risk.

To make such allocation decisions, U.S. Army leaders need to be able to understand and quantify the risks associated with different investment decisions. This is challenging for many reasons, including the complexity of the Army's missions, its set of capabilities, the force structures in which those capabilities reside, and the uncertainty about future conflicts in which the Army might be required to engage. Army leadership must be able to quickly assess the broad implications of changes to high-level force structure and resourcing plans, including changes to decisions about end capabilities, capacity, readiness, force generation, and modernization and acquisitions. The work described in this report focuses on a tool and methodology designed to help understand the force sufficiency component of these questions. The analysis presented here focuses on a specific type of risk related to unexpected future outcomes relevant to national security, namely the risk related to capacity of ready units relative to the demands during future potential conflict. The level of this risk, measured in terms of

[1] In this context, use of the word *right* is not meant to imply that there is a single correct set of military capabilities with all other sets being wrong—that is clearly not the case. *Right* is used here as a shorthand to denote a set of capabilities that is sufficient to support the stated priorities in the assumed operating environment against the projected challenges as needed.

force sufficiency (capacity), is affected by force structure and force generation under uncertainty about future demands.

To enable effective exploration of various force structure options and force generation policies as part of the Army's strategic planning process and development of the Program Objective Memorandum (POM), Army planners need a way to develop quick, first-order assessments of risks and costs associated with those options and policies. The planners need to explore questions of force sufficiency not only across a variety of options and policies but also across a range of possible futures, thus incorporating risk and uncertainty. This report focuses on a tool developed to address this need for fast analysis at a high level, introducing and describing RAND's Multi-Period Assessment of Force Flow (MPAFF) tool. This tool fills a requirement for a quick-turn, rough-order capacity assessment tool that can weigh the effect of large-order changes to force structure, force mix, and force management decisions on the ability to meet demand. The tool provides the ability to explore the capacity of the operational force structure and force generation to meet a variety of peacetime and wartime demands. It also helps us to understand the effect that various policy levers and force management factors have on the ability to meet demand. The tool is quick to run, thus providing the ability to perform timely quantitative assessments of capacity relative to future demand under a variety of force structure and force management policies—a capability not currently provided by other tools available to the Army.

In this report, we present an overview of the MPAFF tool's structure and capabilities and present an illustrative example of how the tool can be used to form the basis of a more holistic evaluation of trade-offs between future investment decisions. The actual application of this methodology to assess force structure and policy options of current interest to Army planners is being reported in a separate document. For this reason, the examples in this report are only illustrative and are presented to explain how the tool works and demonstrate how it can be used. No actual assessment results are included in this report, though we comment on some of the broad trends. The tool presented here is currently being used to support RAND work on force sufficiency for a stress test with a near peer, sufficiency of Army Air Traffic Control capacity, analysis of joint cluster basing, and evaluation of options for broad future Army investment decisions across portfolios.

The focus of this report is how to conduct quick-turn assessments of options and policies against potential strategic futures, as well as against possible budget futures. This report describes an analytic approach that assesses the risk and cost of potential Army force structures and related readiness and force generation policies. It describes the overarching analytic approach and explains how the problem is decomposed into various steps that together provide risk and cost assessments. It also describes the various inputs needed for the assessment process and the models and tools used to perform each of the steps in the process. This report will enable readers to decide whether the MPAFF tools are appropriate for answering their specific questions and will give them an understanding of how the MPAFF tools work. The report assumes a familiarity with Army force management terminology and processes, as well as some experience with simulation modeling and output visualization, especially in Chapters Three through Five.

Motivation and Overview of the Analytic Approach for Quick-Turn Holistic Risk Assessment

Army planners need to quickly evaluate the ability of possible Army force structures and corresponding readiness and force generation policies to meet various strategic demands in an uncertain future operating environment. Quick-turn tools that provide an approximate picture of the impact of resource allocation decisions on force sufficiency allow planners to take a wider aperture in the early phases of planning and address which factors and decisions are "big movers" in terms of the Army's ability to meet demand. This allows them to paint a picture of the trade space implied by various force structure and policy options for their leadership. Such analysis enables them to understand the impact of potential changes on the risks the Army faces in supporting the nation's strategic priorities and the corresponding fiscal implications. This provides Army leadership the information to both advance arguments as to why the risks to U.S. national strategy merit additional funding and to make informed decisions as to how to meet a given fiscal top line.

To be useful in the give-and-take of budget discussions leading up to the preparation and submission of the Army POM, Army planners need an approach that is relatively fast: They must be able to assess options in a week or two (or less). Anything substantially longer than this makes it difficult to fully explore the option space in an iterative fashion. Uncertainty about future demands and the large number of potential force structure and force generation decisions to be made imply that a large number of assessments must be performed to build an understanding of the state space of force sufficiency outcomes. While simplification is critical, modeling must also preserve enough fidelity about force generation processes and the number of ready units they can produce *over time*. To achieve speed while incorporating a time element, the tool developed in this study produces answers that are first-order estimates of period-by-period (generally month-by-month) ability to meet demand, not precise deployment schedules. As the primary purpose is to compare various options, first-order estimates suffice, so long as those estimates reflect the effects of the key options Army leadership desires to explore. The RAND MPAFF provides a tool for quick quantification of capacity risk under different assumptions about

- variations in force structure (changes in the numbers and mixes of force elements), to include variations in enablers and in units at echelons below Brigade Combat Teams (BCTs)

- changes in readiness policies (overall levels of force readiness and the readiness levels of forces when they deploy)
- alternative force generation policies (such as the traditional Army Force Generation [ARFORGEN] policy versus a sustained readiness generation policy, or some combination of these).

RAND has developed two variants of the tool for this work: MPAFF and MPAFF-J. MPAFF is a visual, human-in-the-loop tool that allows users to assess capacity for a particular configuration of these levers visually and quantitatively in a matter of seconds, so long as the necessary inputs are available. If an even broader state space needs to be explored, a reimplementation of the MPAFF tool in the Java programming language, called MPAFF-J (MPAFF-Java), provides a means for assessing many thousands of combinations of these levers within a matter of hours. This reimplementation, discussed further in Chapter Five, allows for the application of a cross-lever data analytics approach to the problem of force sufficiency under a variety of assumptions.

Organization of the Report

This report is organized into five main sections. Chapter Two introduces the landscape of currently available Army Force Sufficiency Assessment models and provides motivation for the creation of RAND's MPAFF. Chapter Three explains MPAFF's overall logic, as well as the inputs required to run the tool and the outputs it can provide to end users. Chapter Four provides illustrative outputs to familiarize readers with MPAFF's capabilities. This is an unclassified illustrative example; actual applications of this methodology will be presented in separate, often classified, reports. Finally, Chapter Five introduces the Java-based reimplementation of MPAFF that enables the running of a large number of MPAFF configurations very quickly, allowing users to explore a larger state space of policy options and possible futures through a cross-lever data analytics approach.

Practical user guides for MPAFF and MPAFF-J can be found in Appendixes A and B, respectively.

CHAPTER TWO

Motivation and Inputs for Capacity Assessment

Capacity assessment investigates whether there are sufficient Army forces to meet potential future demands. Capacity assessment (also called *sufficiency assessment*) is conducted by what is—at least in concept—a straightforward comparison of what the force inventory and force generation policies produce in terms of ready forces and the demands for those forces over time. The comparison can occur at different levels of detail and fidelity, depending on the questions being asked. Capacity assessment can consist of a strategic-level assessment of high-level capabilities or a soldier-level simulation of available forces. To answer the questions regarding resource allocation for force structure and force generation described in the previous chapter, capacity assessment is generally conducted at a unit level. It is common to focus on the largest maneuver force elements, BCTs and Combat Aviation Brigades (CABs); however, given the Army's current interests, it is often appropriate to focus on the battalion level and address a broader collection of unit types (to include enablers). The impacts and stresses experienced by individual personnel are, to some extent, captured indirectly in the unit-level force generation policies, but their explicit inclusion is outside of the scope of this methodology. The set of policy options that can be explored using unit-level tools when conducting capacity assessment includes the following:

- force generation policies and level of force readiness
  - Are ready forces generated using ARFORGEN-based or sustained readiness–based force generation rules?
  - Which ARFORGEN rotation rates apply during each stage of a conflict?
  - How much of a sustained readiness–based force is kept fully ready?
- deployment lengths and extensions
  - What are standard deployment lengths for each unit type? Can unit deployments be extended? Which ones? For how long?
- readiness standards

  - Are fully trained (C1) units required in order to deploy or can some demands be satisfied by less ready (C2) forces?[1]
- use of the reserve component (RC) and National Guard units
  - Which demands can (or must be) be satisfied by these components?
  - In times of a surge, how soon can such units be made available to meet demands?
- order of preference in which units are assigned to demands
  - For example, if both active component (AC) C2 units and RC C1 units are available to meet a demand, should we prefer an RC C1 unit or an AC C2 unit?

Given a force structure and a set of readiness and force generation policies, a variety of tools exist to perform a capacity analysis:

- U.S. Army Training and Doctrine Command (TRADOC) Analysis Center (TRAC)'s Low-Fidelity Supply vs Demand model
- TRAC's System for Periodically Apportioning Demands (SPADES)
- RAND's Peak-Surge Model
- RAND's Force Capacity and Cost Model (FCCM)
- Center for Army Analysis (CAA)'s Total Army Analysis (TAA)
- RAND's Rotational Equipping and Modernization Model.

To distinguish these tools and determine how well suited they are to our purpose, we found it useful to consider four key characteristics of each tool:

- whether the tool assesses demand and supply across time or disregards the time component and assesses only peak demands
- the tool's ability to assess Army forces at different levels of detail (beyond maneuver units like BCTs and CABs)
- how much time it takes to prepare and use the tool
- the tool's fidelity in representing the force generation process, including whether the tool captures the ebb and flow of supply of ready forces over time.

Table 2.1 assesses each of the tools mentioned above based on these key characteristics.

All of these tools are valuable and play important roles in the Army's analytic processes. Our focus is on examining how these might be used in support of quick-turn, macro-level explorations of the cost and risk trade-offs of multiple force structure and/or force generation alternatives. TAA is, of course, the Army tool of record for developing and assessing force structure capacity; however, the time it takes to conduct a TAA and the extremely high level of detail at which it works make TAA unsuitable for our

[1] For more on Army readiness reporting and C-level readiness ratings, see Headquarters, Department of the Army, *Defense Readiness Reporting System–Army Procedures*, Army Pamphlet 220-1, Washington, D.C., November 16, 2011b.

Table 2.1
Key Characteristics of Capacity Assessment Tools

Tool	Source	Assess Supply and Demand over Time?	Includes Units Below BCT/ CAB?	Includes Enablers?	Notional Turnaround Time	Level of Fidelity
Lo-Fi Supply vs Demand	TRAC	No	No, but expandable	No, but expandable	Hours	Low
SPADES	TRAC	Yes	Some, but expandable	No, but expandable	Days	High
Peak-Surge	RAND	No	Yes	Yes	Hours	Low
FCCM	RAND	Yes	Yes	Yes	Weeks	High
TAA	CAA	Yes	Yes	Yes	Months or years	Very high
Rotational Equipping Model[a]	RAND	Yes, for equipment demand only	Yes	Yes	Hours	Low

SOURCE: RAND Arroyo Center analysis.

[a] Christopher Pernin, Edward Wu, Aaron L. Martin, Greg Midgette, and Brendan See, *Efficiencies from Applying a Rotational Equipping Strategy*, Santa Monica, Calif.: RAND Corporation, MG-1092-A, 2011.

purposes of informing senior leaders with an overall picture of force sufficiency across a large state space of policy options and possible futures. On the other hand, the two tools that focus on static, peak demands (TRAC's Low-Fidelity Supply vs Demand tool and RAND's Peak-Surge tool) can provide faster insights on overall inventories of forces, but their inability to reflect the fluctuations in demands and force supply over time makes them unsuitable for exploring alternative readiness policies or force generation models.

The two remaining tools in Table 2.1, SPADES and FCCM, are therefore best suited for exploring how force generation and readiness policies affect the capacity of a given force structure. Both tools are very similar in overall approach and the types of outputs they generate. FCCM is built around a Standard Requirements Code (SRC)–level description of the existing Army force structure and the various integrated security construct (ISC) demands.[2] Therefore, it can compare demand and supply for practically any unit type against any of the ISC demand signals (all available as menu selections). FCCM compares one unit type against one demand signal at a time, and outputs require human review (and potential adjustment) of the computed force flows, making this tool relatively slow, with a normal set of runs taking a couple of weeks.

A faster option is the SPADES tool, which can use any suitable demand signal, including any of the ISC-derived signals. SPADES implements not only the normal ARFORGEN processes but also U.S. Army Forces Command (USFORSCOM)'s best

[2] The SRC identifies the functional unit type of an Army unit. ISCs describe scenarios for combinations of military operations traditionally used for developing capability requirements and understanding force structure requirements.

practices for force management of particular unit types. As a result, it generates realistic force flows for the units without human review. SPADES was originally developed to explore capacity at the BCT level. It has since been expanded to CABs, Echelon Above Brigade fires battalions, air and missile defense units, and Echelon Above Brigade truck companies. While SPADES itself is unit agnostic, expanding SPADES to other types of units or to units below BCTs requires a one-time investment of time researching and implementing the appropriate force management rules for those units.

As noted in Table 2.1, the tools that limit their assessment of capacity to only consideration of peak demands are exceptionally quick to use and permit rapid exploration of alternatives. The tools that assess capacity by comparing demand and supply over time take somewhat longer to use, primarily because of the additional time required to set up the inputs and review force management outputs, which are more complex (the actual run times of the tools are relatively fast and are not the limiting factor). The availability of both very quick but low-fidelity tools and higher-fidelity but somewhat slower tools suggests a practical strategy for exploring a large number of force structure and policy options. The suggested approach would be to use low-fidelity, quick tools to rapidly examine many options (and their combinations) so as to identify which ones are interesting enough to merit more-detailed modeling and examination using higher-fidelity (but slower) tools. Such a triage strategy can be made even more appealing by using a quick-running tool that includes a basic assessment of demand and supply over time (instead of simply peak demands). This is exactly what RAND's MPAFF aims to provide. By creating a more streamlined variant of FCCM that models the basic ARFORGEN force generation processes without including any additional force management complexities, we are able to preserve sufficient fidelity of supply and demand relationships over time without sacrificing setup and run speed, with an MPAFF run completing in a matter of seconds. The tool applies force generation rules mechanically, without any consideration of more-complex force management behaviors specific to the various unit types. While this does not give a completely faithful representation of how the Army would actually meet demands, it is sufficient for seeing the overall effects of alternative force structures and/or policy choices regarding readiness and force generation while remaining fast and easy to use.

RAND MPAFF Features and Required Inputs

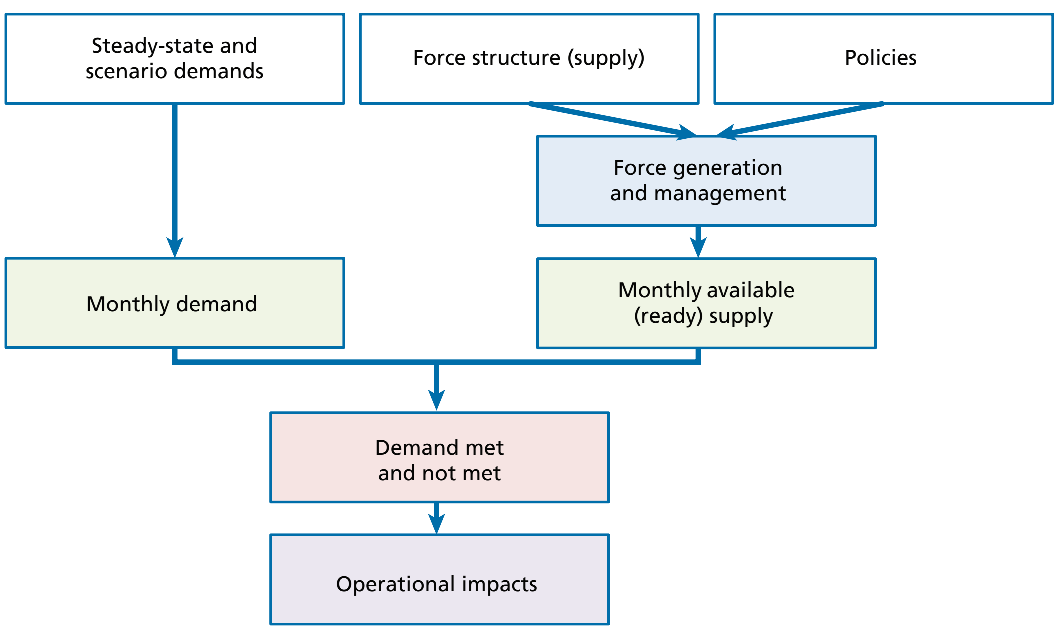
Several features are critical to the ability of RAND's MPAFF tool to fill the analytic gap described in the previous section and allow the Army to explore issues and options of current concern. Specifically, the Army is interested in being able to

- include assessment of the ability to meet demand over time, rather than just peak demands

- capture Army force structure at higher resolution than simply BCTs and CABs (e.g., at the battalion level or below)
- include various Army enablers and force elements that exist outside the BCT structure (e.g., air and missile defense [AMD] units, Combat Service Support [CSS] units)
- examine the effect of changes to the ARFORGEN process
- explore alternative readiness models, such as steady-state readiness or band-of-excellence readiness models
- evaluate the impact of changes to future force structure, including both force size and capabilities mix
- cover a wider array of alternative futures and scenarios in terms of future demand requirements.

To achieve these goals, MPAFF and its Java-based reimplementation, MPAFF-J, require sufficient data on force structure (inventory), future demands, and force generation rules. Given these building blocks, MPAFF conducts a period-by-period (generally month-by-month) comparison of required demands versus trained and ready available units for each unit type. Figure 2.1 illustrates the basic flow of MPAFF's simulation logic. Beginning with the inputs on supply, demand, and policies related to force generation and deployability, the tool calculates the total supply for each unit type (by

Figure 2.1
MPAFF Tool Logic Outline



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component) and readiness levels of each of the units of that unit type for the first modeling period. This yields the monthly supply of ready units. Monthly demand levels are obtained from the applicable scenario force flows and reflect user-specified combinations of demands for Army units to support war fights, as well as worldwide presence. Deployments are assigned and units sent to reset depending on the policy rules previously set by the user, resulting in an assessment of met versus unmet demands for that period. Performing this calculation for each period in turn leads to an overall picture of met and unmet demands. From this information, the final output of the MPAFF tool, decisionmakers can begin to assess operational impacts of shortages and the policy decisions they have chosen to model.

Force Structure Data

To form the supply side of the force sufficiency modeling equation, MPAFF requires details on the force structure for units of interest. Supply data must be supplied at the unit level. The kinds of units and the level of specificity depend on the nature of the question being explored. Many questions today are focused on BCTs and CABs—if that is all that is desired, providing demand data in terms of BCTs and CABs suffices. However, the MPAFF tool allows us to look at force structure at any level below (or above) the level of a BCT, as well as to look at enablers that exist outside of the large maneuver structures. Supply data must be specified only for the units of interest, and the level of granularity can vary from unit to unit and model run to model run. The essential information needed is an actual or potential Army force structure in terms of number of units. The supply-side information on force structure must be detailed enough to generate inventories at the same unit level of detail reflected in the demand signal. For example, if demand for truck companies is to be modeled and evaluated, both the demand signal and force structure information must exist at the truck company level, with the supply and demand analysis based on similar truck company configurations with comparable capabilities.

The ideal source for generating supply inputs that match desired demand signals is Army force structure information described down to the SRC level. This exists for the actual (current) force and for potential future Army force structures programmed in the Army POM. Alternative Army force structures being considered and debated are often not described at this level of detail. However, given a general understanding of what is intended by an alternative Army force structure concept, a reasonable SRC-level force structure representation can be created by adapting an existing SRC-level force structure. For example, if an SRC description exists for a 1,045,000 Army end strength force, a concept for a 910,000 end strength force is expressed in terms of a reduced number of BCTs (by type), and there are no other net changes to overall combat organization and operational concepts, an SRC-level description of the 910,000 force can be generally derived from the SRC-level description of the 1,045,000 force based on making appropriate proportional reductions. To the extent that proposed Army force structures involve more-extensive changes to the composition and/or organization of Army units, defining an SRC-level description will be more complex.

Demand Data

The ability to use SPADES, FCCM, or MPAFF for quick-turn assessments is completely dependent on the availability of appropriate *time-sequenced* demand data. As mentioned above, the RAND MPAFF tool uses a unit-level approach that has the potential for including both large maneuver force elements and smaller units or portions of units; as long as inventory (supply), demand, and rules for calculating readiness over time can be defined at the desired level of analysis, it can be accommodated by MPAFF. For each unit to be included in the model run, time-phased demand data are needed. Time-phased Army demand data for potential future engagements are generally available from three sources:

- Multi-service force deployment documents (MSFDs): These documents are associated with the ISCs and provide time-phased demand data for units at the SRC level.
- Time-phased force and deployment lists (TPFDLs): These force flows are associated with actual operational plans (OPLANs) and provide force-flow data at the SRC level.
- Mobility studies: These are created by various organizations to study specific issues related to the deployment or movement of military forces and contain time-sequenced force flows.

All of these sources are classified and have associated strengths, weaknesses, and biases. Outside of these sources and the limited set of scenarios and operational concepts covered within them, such time-sequenced demand data are not generally available. In particular, such detailed data are not currently available for many scenarios of potential interest to the Army. The set of existing scenarios contains embedded assumptions that may or may not align with Army leaders' professional judgment. To the extent the Army is interested in exploring demand signals beyond those represented by existing MSFDs and OPLAN TPFDLs, it is necessary to develop additional demand signals for use in the MPAFF tool. This may require vetting with the Office of the Secretary of Defense (OSD) and the Joint Staff to verify importance and feasibility. Given such demand signals, first-order assessments of risk and cost for various force structure options can be generated in a straightforward manner.[3]

[3] For one approach that could be useful for rapid cost estimation, see Matthew Wade Markel, Stuart Johnson, Carolyn Chu, David C. Gompert, Duncan Long, and Anny Wong, *How Much Will Be Enough? Assessing Changing Defense Strategies' Implications for Army Resource Requirements*, Santa Monica, Calif.: RAND Corporation, RR-239-A, 2014.

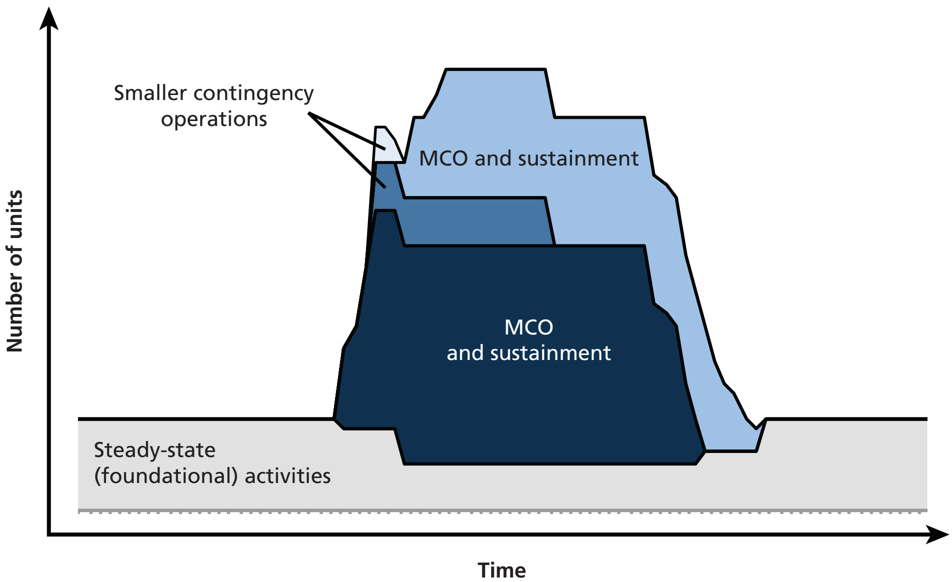
Demand data for the MPAFF tool consists of steady-state and scenario demand data for the units of interest over time. In principle, demands for Army forces are derived from a separate process that examines the nation's strategy, current security threats, broad concepts for countering those threats, and, from these, establishes a set of specific scenarios with corresponding demands for Army forces. Demand signals include demands for force in support of

- Steady-state peacetime activities, including crises of various kinds that fall short of combat (humanitarian/disaster response, assistance to allies, etc.)
- various kinds of combat operations (major combat operations [MCOs], "deny" operations, crises, etc.)
- stability operations that may follow such crises (perhaps including demand for forces used to eliminate weapons of mass destruction and demands for forces to be used in homeland defense missions).

A combination of steady-state activities, war scenarios, and/or stability operations laid out over time produces an overall demand signal that consists of a list of forces and the month-by-month demands for those forces, as seen in the illustrative sand chart in Figure 2.2. Figure 2.2 shows various demands that overlap in time and therefore "stack" on top of each other. Beginning at the bottom, the figure depicts what we notionally think of as a long-term steady-state demand signal that provides the "background" of demands for Army units. Superimposed on this background is what we call a "scenario": a combination of war, crises, and/or stability operations (each represented in a different shade of color) that produce "spikes" (could be prolonged) in demand. MPAFF assumes that steady-state demands are constant over time, except possibly during times of war (as described further in Chapter Three). Scenario demands are represented by a time-phased demand signal whose size and duration is determined by the combination of wars, crises, and/or stability operations the scenario represents. The default setup calls for monthly demand inputs, though the size of the time step could be changed with minor adjustments to the tool. Scenario demand inputs can follow any shape (in terms of demand over time) desired by the user and are not necessarily limited to operations with an initial peak and longer sustainment operations.

The inclusion of time-phased demand signals is what allows MPAFF to explore the ability to meet and sustain demand over time rather than assessing only the ability to supply a peak demand number. *Peak-demand* analyses of sufficiency simply consider the *peak* (highest) demand and assess whether the force structure is sufficient to meet that peak demand. Such methods—which do not consider how long high demands may need to be sustained, nor the ability to generate forces over time—are commonly reported in *stoplight*-style charts that simply indicate whether peak supply exceeds peak demand (green), or falls short (red); cases on the edge are commonly colored yellow. The output from such an assessment, using the illustrative demand signal from

Figure 2.2
Illustration of How Demands Overlay over Time



NOTE: Each color represents a different demand for Army units; the vertical axis represents the cumulative demand for Army units. Different demands occurring simultaneously "stack" on top of each other.

RAND *RR1954-2.2*

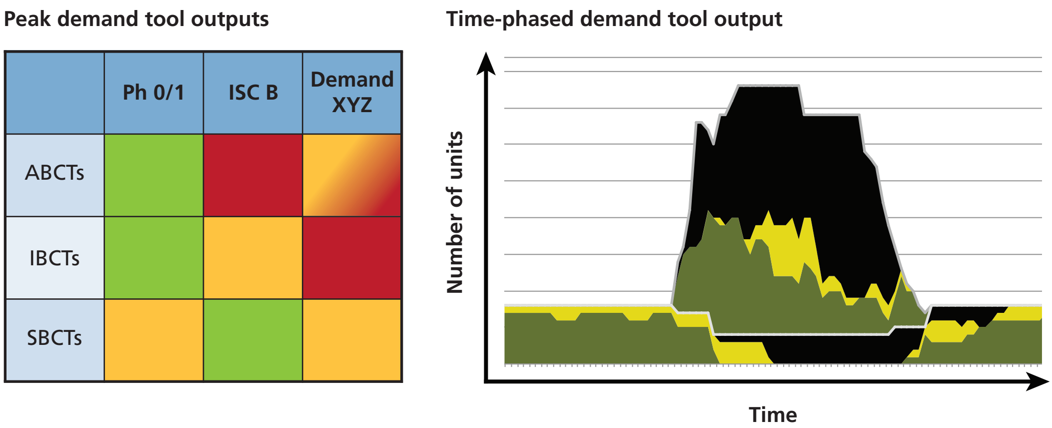
Figure 2.2, is provided in the stoplight chart that appears on the left panel of Figure 2.3. The right panel of Figure 2.3 provides example outputs from tools without time-phased demand analysis. This ability to include time-phased demand is the key feature that distinguishes MPAFF from other quick-turn tools. It is clear that a much larger amount of information is contained in the time-phased (right side) result.

Readiness and Force Generation Data

To benefit from MPAFF's ability to assess force sufficiency period-by-period versus a time-phased demand signal, we must also translate inventory (supply) data into information about available (ready) units over time. In addition to identifying demand and inventory (supply), we need information on the readiness, force generation, and force employment/management models that govern the readiness progression of the units of interest. In general, we need to know the starting readiness state of the force in terms of C-ratings, as well as how long it takes units to move through the cycle of readiness upon a deployment or a reset.

The current implementation of MPAFF includes two primary underlying force generation models, a rotational model and a sustained readiness model. The rotational

Figure 2.3
Peak Versus Time-Phased Force Sufficiency Outputs



NOTE: Peak-demand output (left) assesses sufficiency by simply comparing peak demand to peak supply and (usually) reports the results in stoplight colors (green = sufficient; red = insufficient). Time-phased output (right) provides exact met (yellow and green) and missed (black) demands in each time period.
RAND *RR1954-2.3*

model simulates the ARFORGEN, which is described in Army Regulation 525–29.[4] ARFORGEN is a cyclic force generation model that moves units through a readiness cycle from C5 (least ready) to C1 (fully ready) status based on a so-called *BOG:Dwell* ratio.[5] The ratio describes the speed at which units move through this progression from least to most ready, as well as the amount of time units spend in the "available" period, ready to deploy. The original ARFORGEN concept included a peacetime, steady-state goal of maintaining a 36-month cycle with an overall 1:3 BOG:Dwell ratio (six-month reset period + 21-month training period + nine-month ready-and-available-for-deployment period). A unit deployed during its ready-and-available period would ideally deploy for a nine-month period. The wartime goals under the original ARFORGEN concept call for a 36-month cycle with an overall 1:2 BOG:Dwell ratio (24-month reset/train period + 12-month ready-and-available-for-deployment period). The ARFORGEN concept also includes a wartime mode with over half of available forces operationally deployed, as well as a separate model for units in the RC. The RC model is based on a steady-state cycle of 72 months with a 1:5 BOG:Dwell ratio and a wartime cycle of 60 months with a 1:4 BOG:Dwell ratio. Note that RC units are generally receiving postmobilization training during the first three months of their ready-to-deploy period and, thus, do not deploy to a contingency immediately at the start of

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4 Headquarters, U.S. Department of the Army, *Army Force Generation*, Army Regulation 525–29, Washington, D.C., March 14, 2011a.

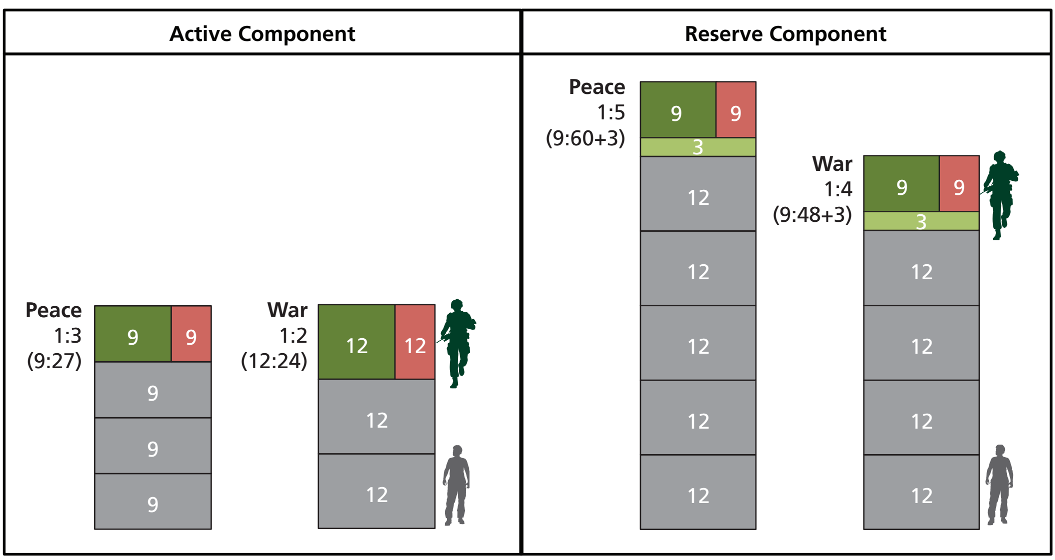
5 Boots on ground:Dwell.

their ready period. A graphical representation of the AC and RC standard and wartime ARFORGEN cycles is provided in Figure 2.4.

The definition of an ARFORGEN BOG:Dwell ratio and a corresponding "basis" period provides the information necessary to define progression through readiness levels over time. For example, a 1:2 BOG:Dwell ratio with a 12-month basis yields the wartime scheme described above. An additional parameter defining the maximum length of deployment when it occurs fully defines the readiness progression.

The second type of readiness model available in MPAFF is a sustained readiness model. The Army is currently working on replacing the ARFORGEN model with sustained readiness as described in Army Regulation 525-30.[6] Sustained readiness could increase the portion of the force that either is maintained at high readiness or can become ready quickly. Fiscal pressures are starting to lead the Army to consider various steady-state or sustained readiness models, as well as combinations of a sustained and cyclical approach. Illustrative versions of a sustained readiness model are preloaded in both MPAFF and MPAFF-J, allowing for initial exploration of the effects of such a change. As with the ARFORGEN option described above, various input parameters

Figure 2.4
Active and Reserve Component Regulation ARFORGEN Cycles



SOURCE: Army Regulation 525-29, 2011.
NOTE: Months spent in BOG state in gray, months spent in Dwell state in green, with deployment durations (in months) shown in red. Light green represents three-month mobilization training period required for units in the RC.
RAND *RR1954-2.4*

6 Headquarters, U.S. Department of the Army, *Army Strategic Readiness*, Army Regulation 525–30, Washington, D.C., June 3, 2014.

can be used to direct the specific behavior of the sustained readiness policy. These are described in more detail later.

The readiness models currently implemented do not include additional constraints related to institutional barriers, such as training space availability. However, many historical or future expected readiness generation models that do include these kinds of barriers could be simplified to fit into the parameters of MPAFF's readiness models. For example, if the existence of a National Training Center constraint tends to add three months to the reset period of a recently deployed unit, model parameters could be adjusted accordingly.

Several high-demand, low-density assets (such as Patriot units) already employ tailored readiness models outside of the ARFORGEN construct. These readiness models can be incorporated into the MPAFF tool through the addition of new modular readiness models. While this is possible in both MPAFF and MPAFF-J, MPAFF-J has been specifically designed to maximize the modularity and, thereby, flexibility of readiness models. Since the simulation is time-based, any complete set of rules by which units move through readiness levels over time could be implemented in the tool.

The final link between demand, supply, and the force generation model that translates supply into a time-phased number of ready units is rules about modes of employment. For example, MPAFF allows users to define the required readiness level or component type required to meet demands under different scenarios. For example, some scenarios may allow only AC forces to meet certain demands; other scenarios may allow deployment of less than fully ready (e.g., C2) units.

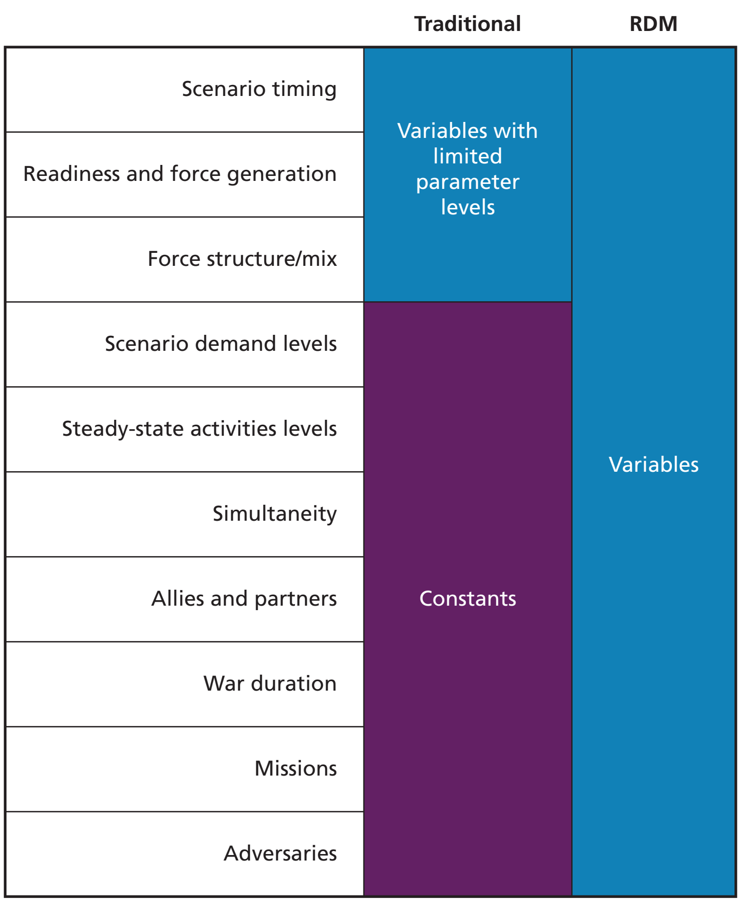
MPAFF–J and the Use of Cross-Lever Data Analytics

The Java reimplimentation of MPAFF, MPAFF-J, provides a run-time optimized alternative to the human-in-the-loop, interactive, user-friendly MPAFF interface for conducting runs. The primary goal of the MPAFF-J reimplementation is to facilitate the running of MPAFF for a large numbr of combinations of the possible levers relating to supply (force size), demand (scenarios), and force management (readiness models). A combinatorial set of runs that cover a large portion of the combinations of these various levers can support data analytics and statistical techniques to identify the key drivers of capacity issues. We call our technique of generating outcomes across multiple levers for analysis *cross-lever data analytics*. We use the outcomes to identify potential strategies robust across a variety of possible futures, characterize the vulnerabilities of such strategies, and evaluate trade-offs among them.[7]

[7] This is similar to a technique called Robust Decision Making (RDM). At this time, we do not hew closely to these specific methods of RDM, as we do not have binary metric definitions of regret as required by RDM. However, RDM is one possible method for analyzing MPAFF-J data. For more about RDM and its development and employment at RAND, see the RAND Corporation's "Robust Decision Making" portal web page, undated.

Using MPAFF-J, we can assess force sufficiency performance under a wide array of possible futures (scenarios) and identify which strategic decisions about force size, mix, and readiness have a significant impact on the Army's ability to meet demand. Instead of focusing on the effect of a small number of possible values for a small number of parameters, we generate the possible outcomes acrosss a variation of parameters, as shown in Figure 2.5. Cross-lever data analytics allow us to examine the trade-offs between diferent force structures in a wide range of scenarios. The ability to explore a large set of possible combinations of future outcomes and policy decisions removes the burden of selecting the most important combinations and prevents accidental oversight of a particular area of the state space where performance is very poor. Additionally, the ability to perform a large number of runs with different configurations, scenario time lines, and assumptions decreases the likelihood that results are driven by simulation

Figure 2.5
Traditional Modeling and Cross-Lever Data Analytics: Differences in Factors Treated as Variable



RAND *RR1954-2.5*

idiosyncrasies, such as startup conditions or random number seeds, or particularly optimistic or pessimistic scenario timing.

Some of the key differences between a traditional approach and the cross-lever data analytics are highlighted in Table 2.2. Application of the cross-lever data analytics, as described in Chapter Five, will allow decisionmakers to take full advantage of MPAFF's ability to provide time-phased assessments of force flows very quickly.

Table 2.2
Comparison of Traditional and Cross-Lever Data Analytics Force Structure Modeling

Traditional Force Structure Modeling	Cross-Lever Data Analytics for Force Structure Modeling
Small number of scenarios provide a limited look at possible futures	Treats every assumption as a variable leading to a possible future state of the world
Hides uncertainty by making specific assumptions	Runs all cases to identify conditions and futures where force structures do and do not meet goals
Small subset of variables considered for defining force structure/policy alternatives	Assesses performance of many possible force structure/policy adaptions against all of these possible futures
Sensitivity analysis varies a few factors at a time	Identifies force structures/policies that succeed over a wider range of futures
Allows for in-depth examination of specific scenarios	Details of specific scenarios may not be easily understood in the aggregated view

CHAPTER THREE

Examining a Specific Scenario with MPAFF

In this chapter, we provide more detail on the structure of the MPAFF tool and include a basic set of instructions for setting up and running the tool. This chapter is not intended to be a comprehensive user guide or provide developer instructions for code modification.[1] Rather, details on inputs, tool structure, and outputs are provided in an attempt to familiarize the reader with the conceptual underpinnings of the tool. Paralleling the set of required inputs described in the previous chapter, we begin by outlining the basic simulation components of supply, demand, and readiness/force generation models.

Quick Start

A current version of the Excel-based MPAFF tool is available to Army users and can be requested from the RAND Corporation's Arroyo Center. The tool comes prepopulated with sample data and illustrative values for all necessary simulation parameters. To run this illustrative sample tool, users must only open the Excel file, enable macros for this workbook, and click the "Run model" button at the bottom of the *Inputs* worksheet. This will run MPAFF with prepopulated sample data and take users to the *Outputs* worksheet. To view sample output, users should select units for which they would like to see outputs and click on the "Generate output plots" button. The rest of this chapter introduces the set of inputs and parameters over which users have control, as well as the outputs users can expect to see upon execution of a run. The majority of concepts introduced in this chapter also apply to the Java reimplementation of MPAFF, MPAFF-J, described further in Chapter Five.

1 A user guide appears in Appendix A.

Basic Tool Components

The basic components of the MPAFF tool include, supply data, steady-state demand data, scenario demands, and the force generation and readiness rules that allow for period-by-period simulations. Demands, supplies, and simulation rules are generally specified for each unit type included in the run.

- **Unit types and number of units (supply):** Each unit type represents a type of force element to be included in the run. For each unit type, supply is specified by the number of individual units of that type available in the force structure. For example, you may have an "Infantry BCT" unit type, and specify the existence of eight "Infantry BCTs" in the supply section of the tool. Unit types may be specified at any level, from a whole division all the way down to an individual soldier, so long as demand and supply are specified at the same level for each unit type and readiness behavior across periods can be defined at that level. In the examples used throughout this report, the unit definition differs conceptually from traditional Army planning concepts of unit design. Specifically, we treat entire combat elements as a single unit, including, for example, headquarters and maneuver SRCs. This is a practical simplification for the types of analysis performed here. This level of aggregation and the size of the units being modeled need not be consistent across different unit types, even within a single model run: A run can simultaneously contain "whole" infantry BCTs, stand-alone infantry BCT headquarter elements, and engineering companies. The only requirement is that supply and demand (see following) be specified at the same level for each individual unit type.
- **Steady-state demand:** The steady-state set of inputs to the tool specifies the expected demand for units outside of a major contingency scenario.[2] In MPAFF, steady-state demands are simplified and represented as a constant demand across all periods, though slight adjustments can be made to these demands in the event of a war scenario. These adjustments are described later in this chapter.
- **Scenario demands:** Scenarios represent demands above and beyond steady-state activities. Each scenario represents operations in a single geographical area, represented by a Combatant Command (COCOM), and demands are specified over time, each period. Scenario demands cover both surge and sustainment operations.[3] Users can select and schedule scenarios for each run and control various

[2] Steady-state demands correspond to activities commonly included in Phase 0/1 of the six-phase Joint Operational Construct. These phases cover shaping and deterrence activities. For more on the six-phase Joint Operational Construct see, for example, U.S. Joint Chiefs of Staff, *Joint Operation Planning*, Joint Publication 5-0, Washington, D.C., August 11, 2011.

[3] Scenarios correspond to activities commonly included in Phases 2/3 and 4/5 of the Joint Operational Construct. Phase 2/3 includes surge operations with seize and dominate missions, while Phase 4/5 covers stability operations.

simulation behaviors for the surge period specifically. For example, deployment extensions may be allowed during wartime, and the requirement for steady-state presence may be reduced. MPAFF also gives users the ability to control force management rules, such as readiness rotation speeds, for the surge and sustainment portions of each scenario, separately. Scenario demand signals can take any "shape" (as defined by demand over time) desired by the user and are not limited to scenarios with an initial peak followed by sustainment operations.

- **Readiness/force generation rules and period-based simulation:** The MPAFF tool approximates time by discrete periods. Readiness models specify how units of a particular type move through readiness levels as time progresses, period to period. The readiness model and associated parameters can be set for each unit type. Two key types of readiness models are already included in the MPAFF tool (one ARFORGEN-based and one sustained readiness–based), though additional readiness models could be added. Throughout this documentation and the tool itself, these periods are referred to as months, because we believe that months are the correct level of analysis for the types of problems that MPAFF is designed to address. Additionally, the existing implementation of ARFORGEN and steady-state readiness models is based on monthly periods. However, the tool is generally agnostic to period length, and a more granular approach (days) or less granular approach (quarters) could be used without making any adjustments outside of the demand inputs, unit rotation/readiness schedules, and readiness model rules.

Inputs

Key MPAFF inputs cover supply (force structure) assumptions, demand for steady state and scenarios, and force generation/readiness rules.

Supply Inputs and Readiness Models

Supply inputs control the size of the force that can be used in fulfilling scenario demand. Supply consists of the types of units available (AC versus RC), the number of units available, and projected force growth.

Baseline Supply

Users can set baseline supply information by unit type. Unit types and their names are specified in the supply section and populated throughout the tool, since demands and force generation rules must be specified for each unit type found in the supply. The tool is agnostic to the level of specificity with which units are defined, meaning that units can be as small or large as desired. For example, some units may be entered at the battalion or brigade level, and others at the company level. The only restriction is that supply and demand must be specified at the same level for a specific unit type. For each unit type, the following information must be specified:

- unit type name
- indicator for whether RC units of this type may be used to fill demand
- number of AC units of this type in the force
- number of RC units of this type in the force
- readiness to be used, with the currently supported readiness models, including
  - rotational ARFORGEN readiness model
  - sustained readiness model for AC units, with ARFORGEN readiness model for RC units
  - sustained readiness model variations for both AC and RC units.

Each of the default readiness models includes additional parameters that can be adjusted to govern the details of the readiness progression by unit type.

For the rotational ARFORGEN model, these include

- BOG:Dwell ratios for the AC and RC during steady state, as well as for the surge and sustainment portion of scenarios
- assumptions about how rapidly the RC becomes available once a conflict has started
- rules governing automatic force growth in a situation where end strength for some unit types increases over time, simulating the creation of additional Army units in times of conflict.

For the sustained readiness models, the parameters include

- the percentage of total available units kept in C1, C2, or less-ready status during peacetime
- inputs that govern the rate at which units become available after a deployment or when a conflict requires less-ready units to advance toward ready status
- an RC mobilization rate that establishes how quickly RC units can complete necessary training in order to participate in a contingency situation. The mobilization rate represents a constraint, such as the need to complete a Combat Training Center (CTC) rotation.[4] RC units are *not deployed to meet steady-state demands* when the RC is using the sustained readiness model as currently implemented.

It is possible to add additional readiness models to MPAFF or make significant adjustments to the existing rotational and sustained models by adjusting MPAFF's underlying code. Modifications that the RAND team has already explored include the

[4] A CTC rotation provides Joint and combined arms collective training at the brigade level.

addition of full RC mobilization, in which RC units can be mobilized at the start of a contingency and be switched to the AC readiness model after initial mobilization. Files implementing this option are available from RAND upon request. Alternative sustained readiness models have also been explored.

Demand Inputs

The user can specify two types of demand inputs: (1) demands for steady-state activities and (2) demands for up to 12 individual scenarios that cover both surge and sustainment operations.

Steady-State Demand Inputs

Steady-state demand is constant over time, though specialty rules about units to redeploy to contingency scenarios or disengage during times of war can reduce steady-state demand signals during some parts of the run.

The basic steady-state demands are specified by unit type and COCOM, where COCOMs include U.S. Africa Command (USAFRICOM), U.S. Central Command (USCENTCOM), U.S. European Command (USEUCOM), U.S. Northern Command (USNORTHCOM), U.S. Pacific Command (USPACOM), and U.S. Southern Command (USSOUTHCOM). For each unit type and COCOM combination, the user must specify how many units are demanded, with a distinction being made between units that are permanently forward-positioned (also referred to as home-stationed) in a COCOM versus those deployed there on a rotational basis. Home-stationed units are treated as though they are always available (ready) by the tool during peacetime, always contributing toward the steady-state demand. Home-stationed units always deploy to a war within their COCOM when it starts and must reset after their deployment, during which time they do not count toward fulfilling war demand. The rate of reset is based on the same readiness cycle used by other units of their type in the current run. Other units must replace home-stationed units while they reset. As long as a war in their area of responsibility continues, home-stationed units continue to rotate through the same readiness cycle as other units of the same type.

In addition to the basic rotational and home-stationed steady-state requirements, users specify two quantities that dictate the level of steady-state demand in times of conflict:

- Some or all of the rotationally deployed units may be deemed "war optional," meaning that demand for these units becomes optional whenever a scenario is ongoing *outside of their COCOM and there is no scenario ongoing within their COCOM*. If sufficient supply is available, all demand (including "war optional" demand) will be filled. However, if sufficient units are not available to meet all demands, the "war optional" units can be allowed to disengage from their steady-state requirement.

- Some or all of the rotationally deployed units may also be deemed "war capable," meaning that they count toward fulfilling scenario demands *within their COCOM* in the event of *an ongoing scenario within their COCOM*. These units essentially redeploy from their peacetime steady-state mission to the war mission as soon as a conflict begins. Deployed units are not moved to another COCOM without going through a reset cycle.

As an example illustrating these rules of steady-state demand reduction in times of war, we might specify steady-state demand for "Unit Type A" in USAFRICOM as shown in Table 3.1.

During peacetime, the steady-state rotational demand to USAFRICOM would be four units of type A. Wartime demand for "Unit Type A" is dependent on where the conflict is occurring and whether sufficient units of type A are available, as shown in Table 3.2.

Scenario Demand Inputs

Any demands above and beyond the baseline steady state are captured in scenarios. Within each of up to 12 scenarios, users can specify specific information about the scenario:

- a scenario description
- the month-by-month demand for each unit type within the scenario

Table 3.1
Example War Demands in USAFRICOM (Rotational)

Rotational Demand	Rotational War-Capable Demand	Rotational War-Optional Demand
4	2	1

Table 3.2
Example Scenario War Demands in USAFRICOM

War Scenario Characteristics	USAFRICOM Steady-State Demand for Unit Type A
Scenario(s) within USAFRICOM requiring *N* units of type A during this period	4–(min(N,2)) units of type A are required for steady state in USAFRICOM. So long as the scenario(s) occurring in USAFRICOM this period require at least 2 units of type A, the 2 war-capable units from the steady-state demand are reassigned to the scenario mission.
Scenario(s) outside of USAFRICOM but no ongoing scenario within USAFRICOM	4–1=3 units of type A are required for steady state in USAFRICOM this period. The 1 war-optional unit of type A is no longer required, signaling an ability to disengage from steady-state operations in times of conflict. Note that if sufficient ready units of type A are available, 4 units of type A will be deployed against both the required and optional USAFRICOM steady-state demands.

- COCOM where this scenario takes place (affecting the degree to which steady-state units can be reallocated)
- month of the scenario in which surge starts and ends, separating surge from sustainment operations and affecting some force management rules, as described later
- whether AC and RC, ready and less-ready forces of a particular unit type may be deployed to satisfy the demands of this scenario.

To build the full demand stack over time and aggregate the steady-state and scenario demands into a period-by-period demand signal, the user must specify the starting months for all of the scenarios to be included in the run. Scenarios do not need to be entered in chronological order. However, the tool will attempt to fill scenario demands in the order in which they are specified in this list in each period. This allows for some control over prioritization across scenarios. War scenario demand is prioritized over steady-state demands. Scenarios may overlap or even begin in the same month.

Additional Run Parameters

Several additional run parameters can be adjusted to control the way in which ready units can fill the aggregated demand signal. These include prioritization across the different components and readiness levels, as well as information about deployment length.

Prioritization

The user may globally disallow the use of specific components and readiness levels of units, namely AC C2, RC C1, and RC C2 units. AC C1 units are always allowable to fill demands, though their use may be explicitly disabled for a particular scenario within that scenario's inputs. If AC C2, RC C1, or RC C2 units are allowed to deploy, the user must also specify a priority ordering for the allowed readiness levels. Limitations on possible prioritizations exist; a C2 unit may not be used before a C1 unit from the same component, and RC is generally used after AC (unless AC use is specifically prohibited for that unit type/scenario). In the run, higher-priority units will be used to fulfill demand first, whenever available.

Extensions

Users may also specify the length of deployment extensions. While each readiness model's settings will include a standard deployment length, the length of deployments may be extended from the default length both in steady state and while a scenario is ongoing. Extensions are added to the default deployment, and wartime (scenario) extensions are added to steady-state extensions when any scenario is ongoing if both are nonzero values. Once a particular unit is extended, it stays extended even if all ongoing scenarios end during its deployment. The exception is a special setting that ends all extensions when war ends. If demand winds down quickly at the end of a scenario, units will end their deployments early if they are no longer needed, since units for which there is no demand will be sent to reset. At the end of a conflict, as demand draws down, the longest-deployed units of a given unit type will be sent to reset first.

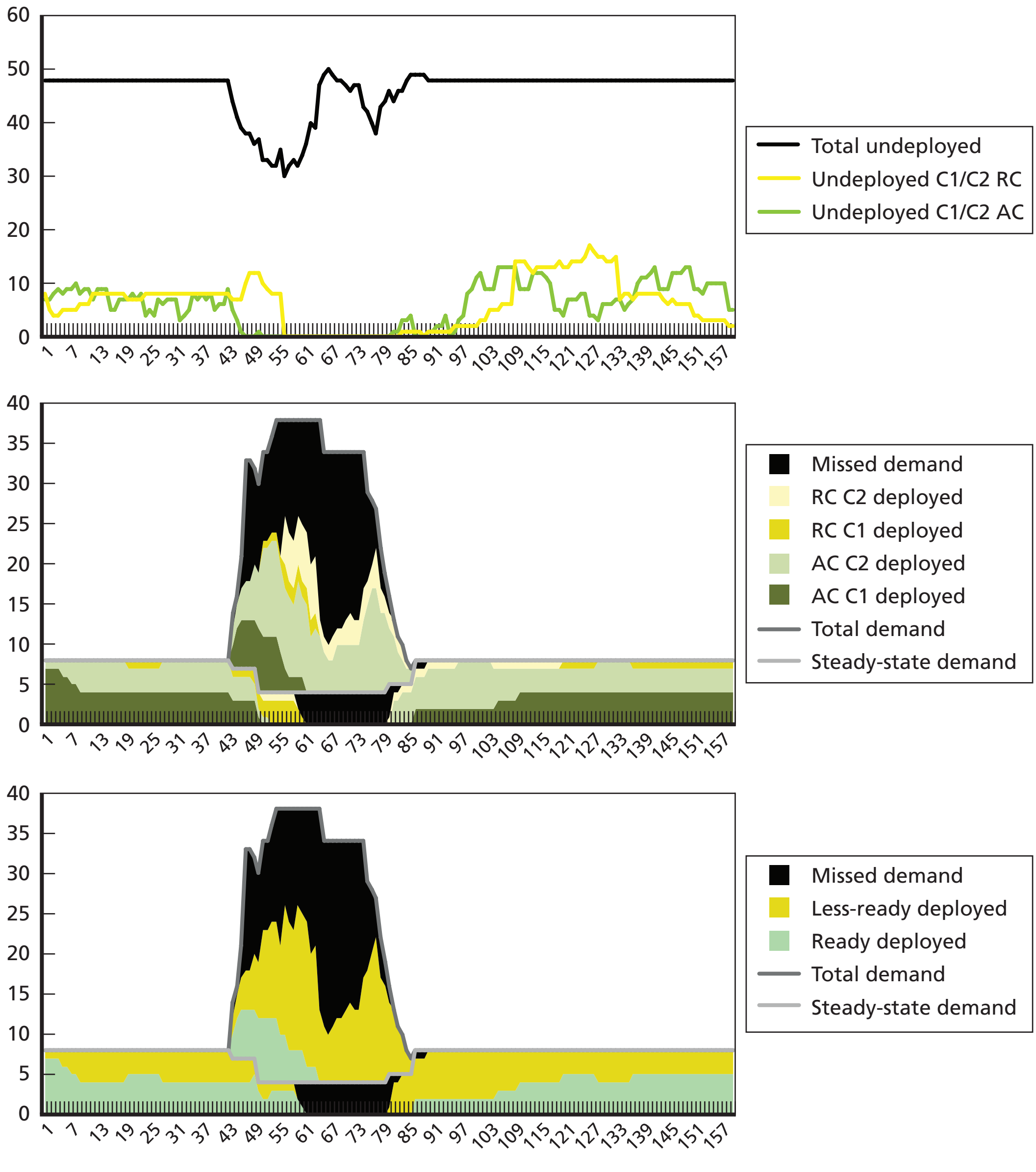
Outputs

Upon executing a simulation run, outputs can be viewed in both tabular and graphical forms. The outputs from the Excel-based version of MPAFF detail all behavior across all unit types for each simulation period, allowing for creation of customized output tables or graphics. While MPAFF-J generates the same set of information during its simulation runs, the size of the output data files over a large number of runs prevent all of this information from being stored. For more detail on the aggregated and reduced set of output data available from MPAFF-J, see Chapter Five. The complete set of output statistics, which is directly available in MPAFF and forms the basis for outputs from MPAFF-J, includes the following pieces of information for each unit type and period:

- total demand across steady state and all scenarios in this period
- steady-state demand in this period
- the number of deployed units in this period
  - to steady-state demands, by component and readiness level (C1 or C2) at time of deployment
  - to scenario demands, by component and readiness level (C1 or C2) at time of deployment
- missed scenario demand in this period
- missed steady-state *required* demand in this period; missing "optional" steady state demand results in a reduction of the steady-state (and total) demand in that period, rather than missed demand
- the number of undeployed units, by component and readiness level (C1 or C2).

In the Excel-based MPAFF tool, unit-level results can also be aggregated across multiple unit types by summing the results from individual unit types. Note that results are aggregated by number of units, so aggregate results for unit types of very different sizes may become difficult to interpret. The Excel-based MPAFF tool creates three automatic output plots, for either individual or aggregated unit results. Samples of these plots are shown in Figure 3.1. The top panel of Figure 3.1 plots the number of undeployed units over time, giving some idea of the percentage of the total force structure for a unit type or set of unit types employed. The second panel shows met and missed demand, with met demand broken out by component and readiness level of the deploying units. Green shading indicates demand met by AC units (darker green

Figure 3.1
Illustrative Raw MPAFF Tool Outputs



NOTE: Vertical axes represent number of Army units; horizontal axes represent time in months. Top panel shows number of deployed and undeployed units over time. Middle panel shows how available units fill demand, with AC units in green, RC units in yellow, missed demand in black, and readiness status indicated by shading. Bottom panel also shows how available units fill demand, with deployed units broken out by more ready (C1) units (green) and less ready (C2) units (yellow).

RAND *RR1954-3.1*

for C1 units, lighter green for C2 units), while yellow indicates demand met by RC units (darker yellow for C1 units, lighter yellow for C2 units). Black indicates missed demand. The third panel of Figure 3.1 also plots met and missed demand, distinguishing only between fully ready units (green) and less-ready units (yellow). Many additional output graphics or tables can be created from the raw data tables available in MPAFF, allowing decisionmakers to create tailor-made displays that address their key questions of interest.

CHAPTER FOUR

Sample Outputs from the Excel-Based MPAFF Tool

To illustrate how the MPAFF methodology can be used to explore force structures and policies on readiness and force generation, we have worked an illustrative example. Our focus is on demonstrating how the effects of policy options can be visualized and compared, not on providing insights for a particular policy issue. This example is also not intended to make definitive statements about Army capacity. We have selected a sample of representative unit types, several options for associated inventories, an illustrative demand signal, and a set of variations on force generation and readiness policies to explore. The different inventory options roughly represent possible future Army inventories at different end strength levels. The illustrative demand signal is representative of the "defeat-deny" construct. Force generation and policy options reflect several excursions on the ARFORGEN construct, as well as a RAND-devised version of a future sustained readiness-based model.

Illustrative Inputs

For purpose of this illustrative example, we focused on the Army's three types of large ground maneuver brigades:

- Infantry Brigade Combat Team (IBCT)
- Stryker Brigade Combat Team (SBCT)
- Armored Brigade Combat Team (ABCT).

To highlight MPAFF's ability to model enabler and more-granular units, we also include a company-level engineering asset:

- Engineer Company, Horizontal.

For the purposes of this illustrative example, we have selected the two force structure options described in Table 4.1. These options parallel estimates of possible future

Table 4.1
Unit Inventories Used for the Illustrative Example

	1,045K End Strength Illustrative Force		910K End Strength Illustrative Force	
Unit Type	**AC Inventory**	**RC Inventory**	**AC Inventory**	**RC Inventory**
IBCT	14	18	7	15
SBCT	8	1	8	1
ABCT	9	6	8	4
Engineer Company (Horizontal)	9	71	9	68

force structure options for a 910,000 end strength Army.[1] These estimates are illustrative and are not intended to represent actual Army decisions or future plans about unit-count inventories or unit configuration.

For this illustrative example, we use a demand signal approximately representative of that used during Army force structure deliberations that took place during the summer and fall of 2013, which consisted of a steady-state demand, a "defeat" scenario represented by an MCO, and a "deny" scenario requiring a lower level of Army support. Associated demands for homeland defense and consequence management in the United States are also included. Our demand signals are also similar to those used by Pippin and colleagues in their recent study.[2] Specifically, we used

- a steady-state demand of about eight Army BCTs (a mix of IBCTs, SBCTs, and ABCTs).
- a defeat scenario demand equivalent to approximately 20 Army BCTs with an additional four-BCT follow-on force. These month-by-month demands are generally representative of a force flow that one might see in a TPFDL for an OPLAN of this magnitude but do not represent any particular TPFDL. The defeat scenario comes with demands for a contingency follow-on, representative of the demands for a possible branch plan being executed.
- a deny scenario demand of approximately ten additional BCTs that begins three months after the start of the defeat operation.
- a short-term BCT homeland defense scenario demand of three BCTs for addressing possible consequence management needs.

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[1] The 1,045,000 force comprises 490,000/350,000/205,000 for the AC/National Guard/Army Reserves. The 910,000 force comprises 420,000/315,000/175,000.

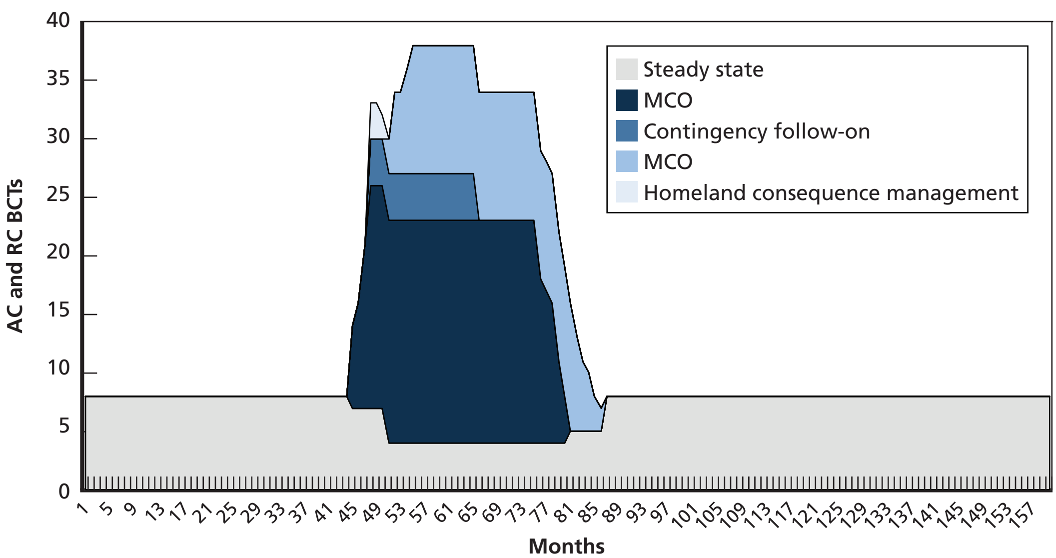
[2] B. Pippin, R. Pace, S. Cunningham, R. Schemm, and W. Castleberg, *Army End Strength Analysis*, U.S. Army Training and Doctrine Command Analysis Center, TRAC-F-TR-14-012, May 2014.

A visual representation of this demand signal aggregated across the three types of BCTs is provided in Figure 4.1.

The force generation and readiness policies used in this example include two ARFORGEN-based excursions, as well as two variations of a RAND representation of a possible sustained readiness approach. An overview of the readiness options explored in this chapter is provided in Figure 4.2. The "standard" and "extreme" ARFORGEN-based models in the top panel parallel the original ARFORGEN concepts outlined in Army Regulation 525–29 and described in Figure 2.4.[3] In addition to differences in the BOG:Dwell ratio between the two ARFORGEN options for the AC during wartime, there are differences in the required level of readiness for deployment and the speed of RC mobilization. In the "standard" case, only fully ready C1 units may deploy, and RC BCTs require a whole year of warning before deploying to contingency operations. In the "extreme" case, AC units may deploy at a C2 readiness level, and the delay for RC BCT units is cut in half.[4]

The sustained readiness options in the bottom panel of Figure 4.2 replace the cyclical readiness model with one in which a particular percentage of total force inven-

Figure 4.1
Army BCT Demand in Illustrative Demand Signal

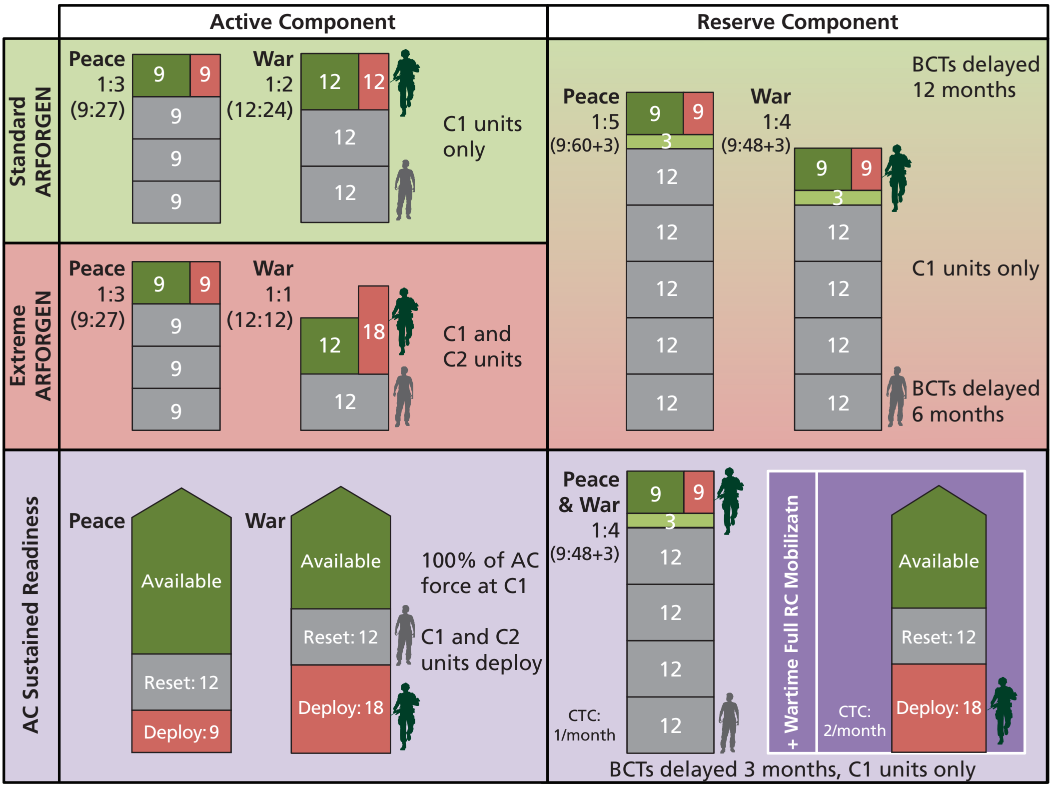


RAND *RR1954-4.1*

[3] Headquarters, U.S. Department of the Army, 2011a.

[4] For units other than BCTs, the number of months of warning required will vary. However, the time required is consistently shorted under the "extreme" assumptions compared with the "standard" assumptions. Delay times used in the illustrative examples are loosely based on First Army estimates of time required for mobilization activities.

Figure 4.2
Readiness Options Explored in the Illustrative Example



NOTE: Months spent in BOG state in gray; months spent in Dwell state in green, with deployment durations in red; for RC units, light green represents the three-month mobilization training periods. For the Sustained Readiness models, the period of availability continues indefinitely until a unit is deployed, and then deployment duration and reset cycle apply.
RAND *RR1954-4.2*

tory is kept at each readiness level during peacetime in the AC. For the purposes of this example, we have selected an extremely optimistic version of a sustained readiness model, where 100 percent of AC units are kept at a C1 level of readiness unless deployed. Upon completion of deployment, these units go through a one-year reset period and once again enter C1 status. We assume that deployments are nine months during peacetime and up to 18 months during war, with both C1 and C2 AC units allowed to deploy. On the RC side, BCT units follow the model described at the bottom right of Figure 4.2. The limiting factor for RC BCT availability is related to mobilization constraints and, most notably, the need to perform a CTC rotation prior to deployment. We assume that one RC BCT per month can complete such training and that RC BCTs follow a 48-month reset time line plus a three-month training period after deployment during wartime. For enabler (non-BCT) RC units, the "extreme" ARFORGEN model applies whenever AC units follow a sustained model.

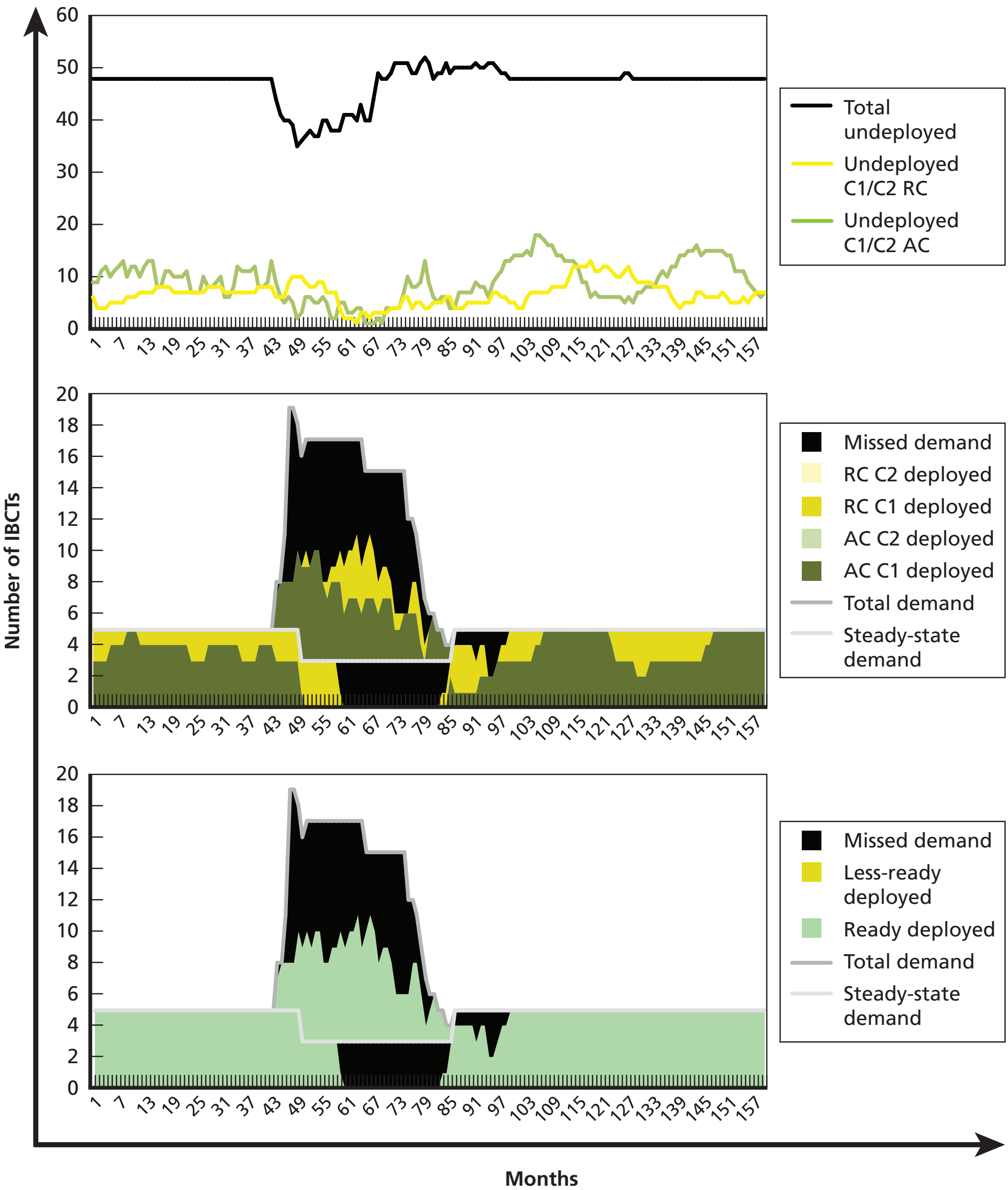
A fourth readiness option explored in this illustrative example further pushes the RC BCT force, implementing full RC mobilization during wartime (see darker purple box in Figure 4.2). The full RC mobilization excursion is one of the examples of additional readiness models that can be programmed to supplement those already included in the MPAFF model. In this model, the sustained readiness options from the previous paragraph apply, with RC units moving to an AC-like sustained readiness model after initial mobilization. Once the simulation enters wartime operations, all RC units move toward full readiness (C1) and follow the same deploy/reset/available model as wartime AC units, essentially "changing" into AC units for the duration of the war scenario. The limiting factor on this process is again CTC rotations, with two BCTs able to complete such a rotation each month.

Understanding the Automated Output Charts

The Excel-based MPAFF tool provides three automated output charts, as introduced in Figure 3.1 in the previous chapter. To provide a better understanding of these output charts, we begin by closely describing them for a single unit type under one set of demand and policy assumptions. Specifically, Figure 4.3 shows the three output graphs for IBCTs using the illustrative demand signal described above, a 1,045,000-based force structure, and the standard ARFORGEN readiness model as in the top panels of Figure 4.2. Figure 4.3 captures several dimensions of the IBCT force's ability to meet demands under the foregoing assumptions:

- The horizontal axis represents time in months.
- The vertical axis represents the number of units of the type under consideration (in this case, IBCTs).
- The top panel of Figure 4.3 explores how much of the ready force is potentially available to meet demands:
  - The black line represents the total number of undeployed units (in this case, IBCTs) over time, giving an idea of how much of the total force remains unused.
  - The green line represents the total number of undeployed ready (C1 or C2) AC units, giving an idea of how much of the ready AC force remains unused.
  - The yellow line represents the total number of ready (C1 or C2) RC units, giving an idea of how much of the ready RC force remains unused.
- The middle panel of Figure 4.3 explores the number of deployed units by readiness level and component, as well as the amount of missed demand:
  - The top solid dark gray line represents total demand for this unit type (IBCTs). Total demand means the sum of the applicable steady-state and scenario (in this case, defeat, deny, and homeland security) demands.

Figure 4.3
Automated Output Graphs, IBCTs at 1,045,000 End Strength Under Standard ARFORGEN Policies



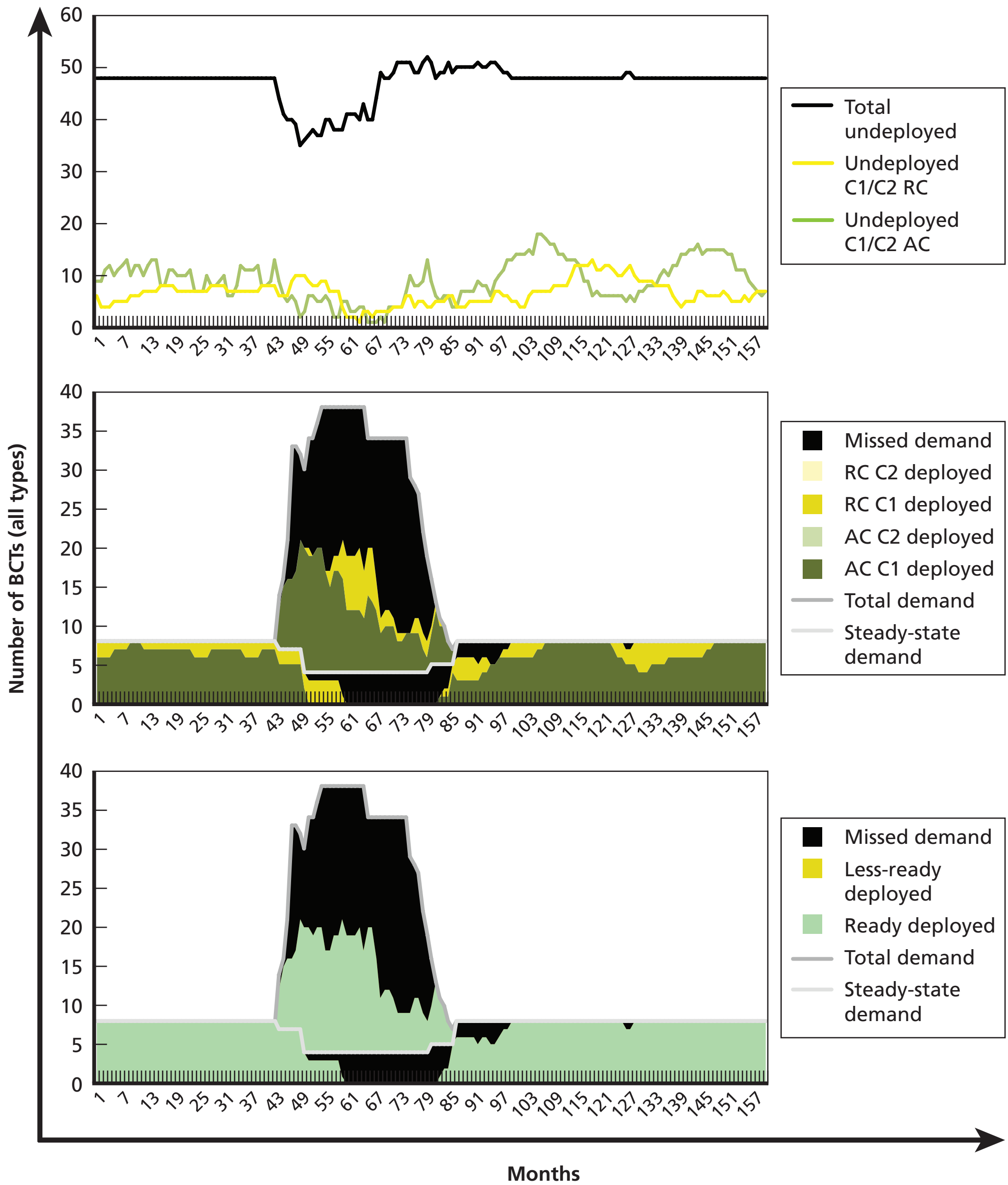
NOTE: For additional figure explanations, see note under Figure 3.1, as well as description in this section.
RAND *RR1954-4.3*

  - The solid lighter gray line represents total steady-state demand for this unit type (IBCTs). Note that this demand is constant in peacetime but may dip down during times of war—as it does in this example. This is due to the ability to disengage from steady-state activities while a scenario is ongoing, as described in Chapters Two and Three.
  - The colors of the areas under these lines indicate whether and how demand is being met.
    - Black areas represent unmet (missed) demand. War demands are preferentially filled over steady-state demands. However, black areas may appear in the war demand and not in the steady-state demand because units may have been committed to steady-state demands prior to being needed for war. No "force management" outside of the standard rules of the selected readiness model occurs; once units are deployed to steady-state commitments, they complete those deployments and are not swung from one demand to another. A lack of sufficient ready units during the second half of the contingency period means that IBCTs completely disengage from steady-state activities during this time, as shown by the large black block under the lighter gray steady-state demand line.
    - Green areas represent demand met using AC units. Darker green units are at fully ready C1 levels, while lighter green represents C2 AC units. Note that no light green is seen in Figure 4.3's middle panel, since C2 units are not deployed when the standard ARFORGEN readiness model is used.
    - Yellow areas represent demand met using RC units. Darker yellow units are at fully ready C1 levels, while lighter yellow represents C2 RC units. Note that no light yellow is seen in Figure 4.3's middle panel, since C2 units are not deployed when the standard ARFORGEN readiness model is used.
- The lower panel of Figure 4.3 represents the same information as the middle panel but simplifies the graphic by distinguishing only between ready and less-ready units (omitting the distinction by component, AC versus RC).
  - Black areas again represent missed demand, while green areas show demands met by fully ready (C1) units, and yellow areas show demands met by less-ready (C2) units. Note that no yellow shading appears in the bottom panel of Figure 4.3, since C2 units (regardless of component) are not deployed when the standard ARFORGEN readiness model is used.

To illustrate the flexibility of the Excel-based MPAFF tool, Figures 4.4 and 4.5 provide additional automated output graphics that can be generated from the same simulation run used to generate Figure 4.3. In Figure 4.4, we show additive results for all three types of BCTs. Figure 4.4 is generated by selecting IBCTs, SBCTs, and

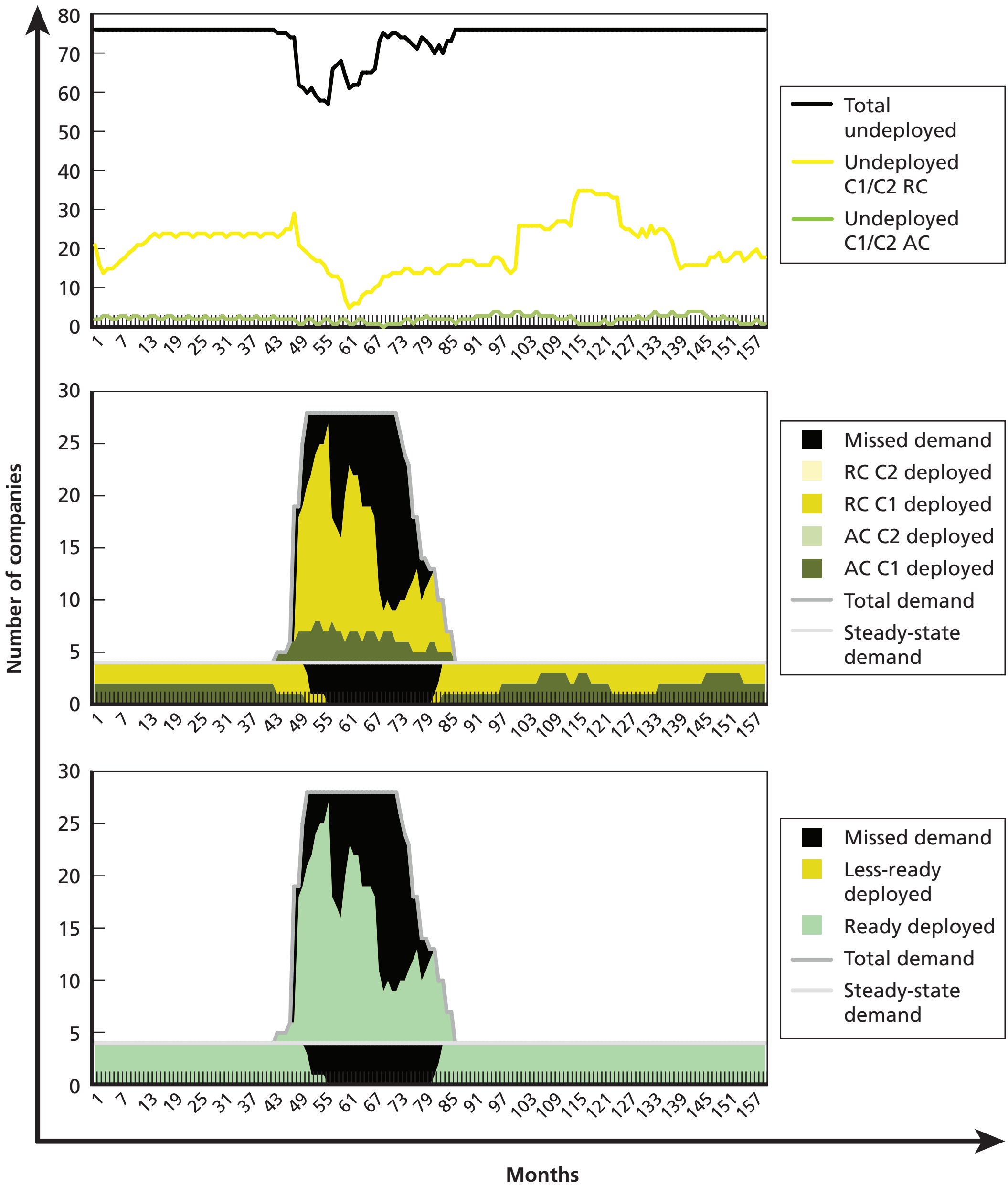
ABCTs simultaneously in the output section of the tool, immediately giving an idea of force sufficiency across all three types of BCTs. Note that the shape of the demand curve in Figure 4.4 is the same as that presented in Figure 4.1. We see that performance

Figure 4.4
Automated Output Graphs, All BCTs at 1,045,000 End Strength Under Standard ARFORGEN Policies



NOTE: For additional figure explanations, see note under Figure 3.1, as well as description in this section.
RAND *RR1954-4.4*

Figure 4.5
Automated Output Graphs, Engineer Company (Horizontal) at 1,045,000 End Strength Under Standard ARFORGEN Policies



NOTE: For additional figure explanations, see note under Figure 3.1, as well as description in this section.

RAND *RR1954-4.5*

across all BCT types is similar to performance of IBCTs alone, with some increased challenges in sustaining a long tail of high demand during the second half of the contingency stack.

Figure 4.5 again shows the same automated output, now for the company-level horizontal engineering element. The scale on the vertical axis is now the number of companies rather than the number of brigades, but simulation logic and output interpretation remain the same. For engineer companies and many other enabler units, a large portion of Army force structure exists in the RC, resulting in a high level of RC usage throughout. Also, a shorter mobilization delay for smaller units means that RC units are able to deploy relatively soon after the start of a contingency.[5] The company-level element simulation run can be executed at the same time as the brigade-level run.

Varying Simulation Inputs

The primary strength of the Excel-based MPAFF tool is its ability to support quick excursions on assumptions about possible futures and policy levers related to demand, force structure, and force generation policy assumptions. In this section, we demonstrate how the effects of these policy levers and assumptions can be explored immediately through the automated output graphs.

We begin by changing the demand signal against which we measure performance of our force. Again looking at additive results for all three types of BCTs, we examine force sufficiency for a smaller demand signal that uses a shortened version of the "defeat" scenario without an additional follow-on force and a very small two-BCT "deny" force for the second scenario. Steady-state demands remain the same. To run the tool with this configuration, a user would simply edit the demand signal for the "defeat" scenario and exclude the other contingency scenarios from the simulation run in the *Inputs* section of the tool. Figure 4.6 displays outputs for this smaller demand signal across all types of BCTs using the standard ARFORGEN policies and the illustrative 1,045,000 end strength force. We see an improvement in overall ability to meet the smaller demand rather than the original larger signal shown in previous graphs. This output also very clearly illustrates an interesting result that would be missed when performing only peak demand analysis: The time-phased results show that the number of available ready units in the postwar period is highly cyclical, since the large number of units deployed to the war effort all enter a reset period at the same time (at the end of the war). While this is an issue that would be addressed by additional force management actions (for example, selective reset in theater), awareness of this effect could be important to policymakers.

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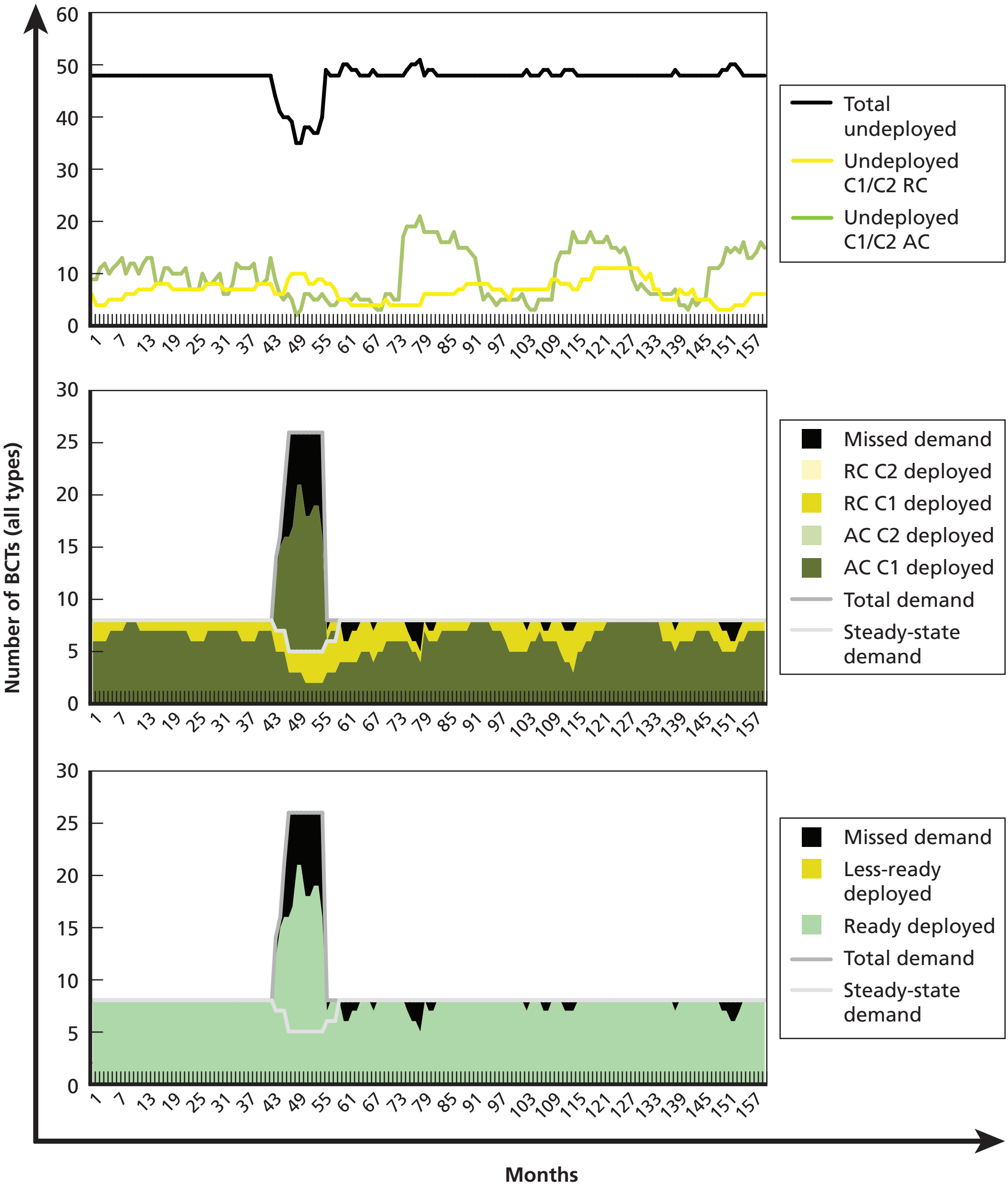
5 An RC delay of five months is used under standard ARFORGEN assumptions for Engineer Companies (Horizontal). This is again based on mobilization timing estimates from First Army.

Figure 4.6
Automated Output Graphs for Smaller Demand Signal, All BCTs at 1,045,000 End Strength Under Standard ARFORGEN Policies



NOTE: For additional figure explanations, see note under Figure 3.1, as well as description in this section.
RAND *RR1954-4.6*

We can also choose to explore the effects of end strength on ability to meet demand. Returning to our original "large" demand signal, Figure 4.7 shows the results of force sufficiency analysis across the three types of BCTs when using our illustrative 910,000 end strength force. As expected, ability to meet demand falls significantly during both the war and steady-state periods. Ability to meet steady-state demand is especially diminished in the postwar period.

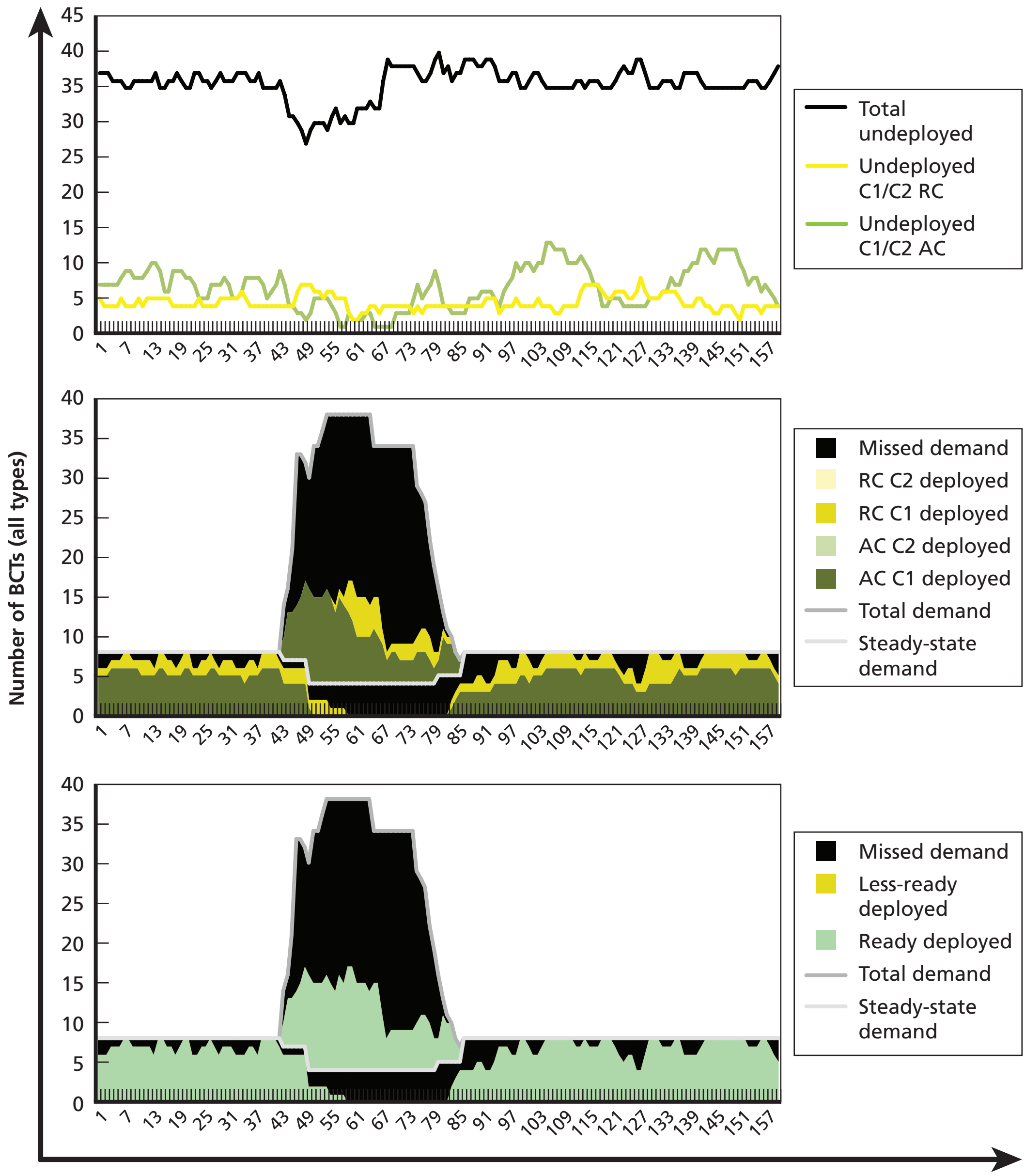
Finally, we are able to quickly and easily explore the effects of alternative force generation and readiness models. As we will see here and in the next section, these sorts of policies can have a very significant effect on ability to meet demand. We again return to our baseline "large" demand signal and run analysis using the 1,045,000 end strength force for all three types of BCTs. However, we now allow the more "extreme" ARFORGEN rotational policies to be applied to the force. As described earlier in this chapter, the "extreme" ARFORGEN policies increase the rotation rates for AC units during both peace and war and reduce the time required for RC mobilization. This results in the force sufficiency assessment presented in Figure 4.8. We see a significant improvement in the ability to meet demand. Note that the ability to ramp up demand at the start of the conflict is improved, and that the force is able to maintain some steady-state presence for a longer period. Also, we now see lighter green shading in the middle panel of Figure 4.8, as well as yellow shading in the bottom panel, representing the now-allowable deployment of C2 AC units. Another interesting observation from this figure (which would not be picked up in analysis of peak demands only) is the switch to almost entirely AC C2 units in the sustainment phase of the war period; the deployment of C2 units in the face of large demands consumes all available C2 units, meaning that units do not have an opportunity to ever reach C1 readiness during the rest of the wartime period.

Creating Customized Output Graphs

A second major strength of the Excel-based MPAFF tool is that it provides a complete set of numerical outputs over time for each unit type. The information provided in the numerical output table is detailed in Chapter Three. The unit-level results can be easily aggregated across multiple unit types through the selection of the desired types in the *Outputs* section of the tool. From either unit-level or aggregate output tables, users can create custom figures that highlight the most-interesting results or compare performance across different configurations.

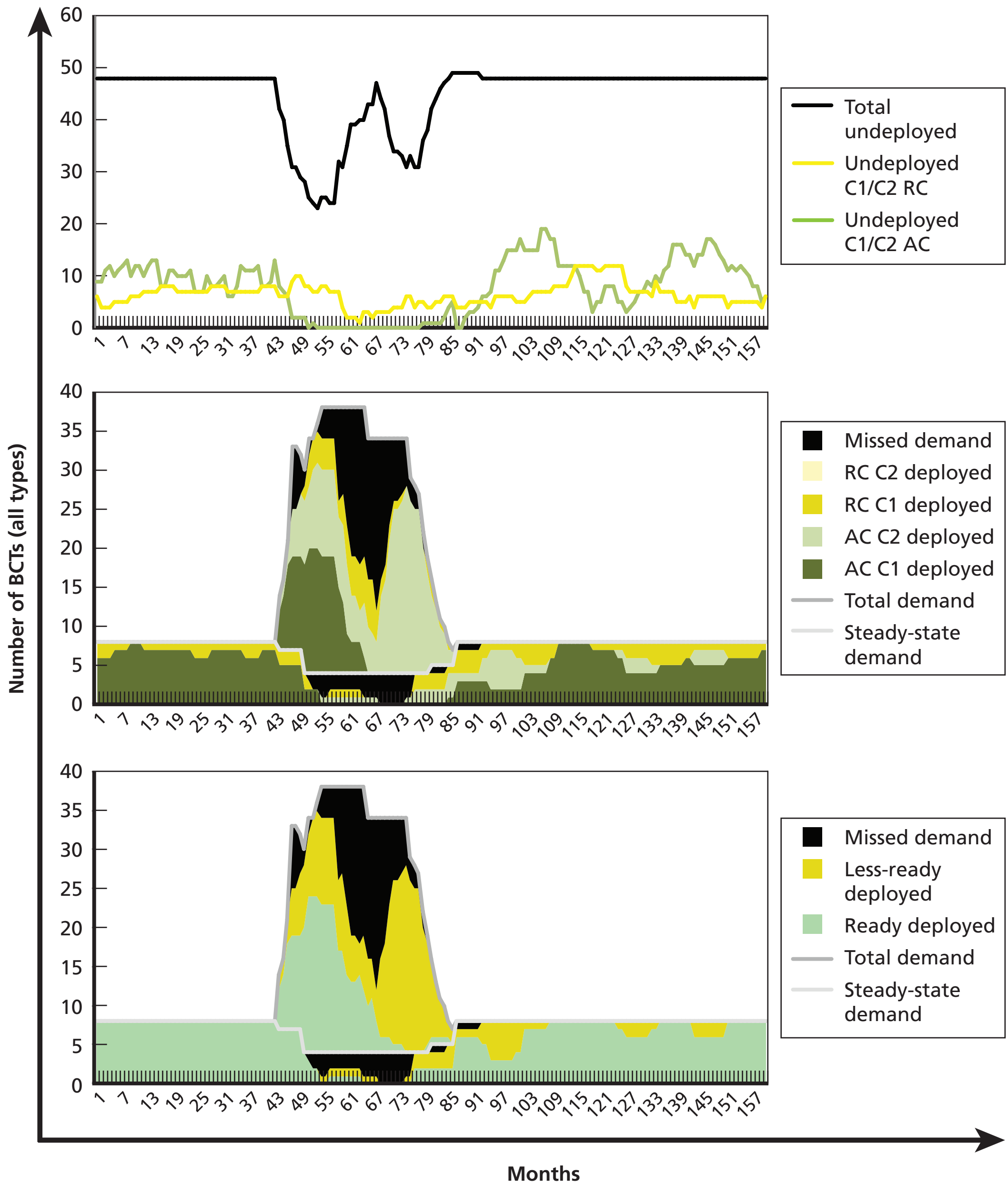
Figure 4.9, for example, illustrates the difference in performance between various end strength options in a single graphic. It essentially combines the data previously displayed in Figures 4.3 and 4.7 to illustrate force sufficiency differences under standard ARFORGEN assumptions between the 1,045,000 and 910,000 end strength forces. The orange line represents demand met using the larger 1,045,000 force, while

Figure 4.7
Automated Output Graphs, All BCTs at 910,000 End Strength Under Standard ARFORGEN Policies



NOTE: For additional figure explanations, see note under Figure 3.1, as well as description in this section.
RAND *RR1954-4.7*

Figure 4.8
Automated Output Graphs, All BCTs at 1,045,000 End Strength Under Extreme ARFORGEN Policies



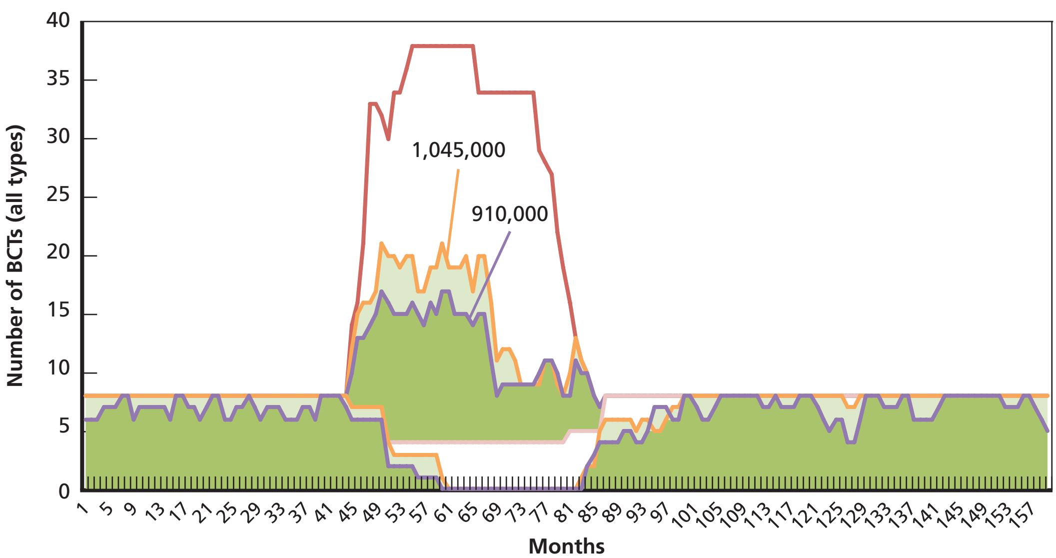
NOTE: For additional figure explanations, see note under Figure 3.1, as well as description in this section.

RAND *RR1954-4.8*

purple highlights the demand met by the smaller 910,000 force. Darker green shading fills the portion of demand that can be met by either the 1,045,000 or 910,000 force, while light green shading indicates demand met only by one end strength level or the other. In general, light green highlights improvements of the 1,045,000 force over the 910,000 option. Customized graphics also allow for improved aesthetics. The black fill previously used for missed demand is replaced by no fill at all, with "empty" space signifying unmet demand. The standard gray outlines are replaced with darker (total demand) and lighter (steady-state demand) red lines to highlight the importance of these overall demand outlines. We could generate similar comparison graphics to highlight differences across force generation policy options or component mix.

The MPAFF tool already provides the ability to explore many different force generation policies, with the potential to add more readiness schemes at a future date. Figure 4.10 provides one possible means for displaying differences in performance across multiple force management options. Each panel shows performance for the 1,045,000 force across all three BCT types under our standard demand signal, but the

Figure 4.9
Customized Output Graph Highlighting 1,045,000 Versus 910,000 Performance Differences, All BCTs Under Standard ARFORGEN Policies



NOTE: Red outlines indicate demand over time. Green fill indicates met demand, with darker shading showing demands met at both 1,045,000 and 910,000 end strength. Lighter green represents demand met by only one of the alternative end strengths in that period.
RAND *RR1954-4.9*

force generation option varies between panels. The four models displayed here mirror the options outlined in Figure 4.2:

- The top left panel is the standard ARFORGEN model, allowing only fully ready units to deploy.
- The top right panel is the extreme ARFORGEN model, with faster rotation speeds, shorter RC delays, and access to C2 units.
- The bottom left panel shows results from the sustained readiness model with 100 percent of the AC kept at C1 status. Overall performance is similar to the extreme ARFORGEN option, though more of the forces filling demand are fully ready (dark green).
- The bottom right panel shows the same 100 percent C1 AC sustained model with the addition of a sustained readiness model with full mobilization for the RC, which again improves performance.

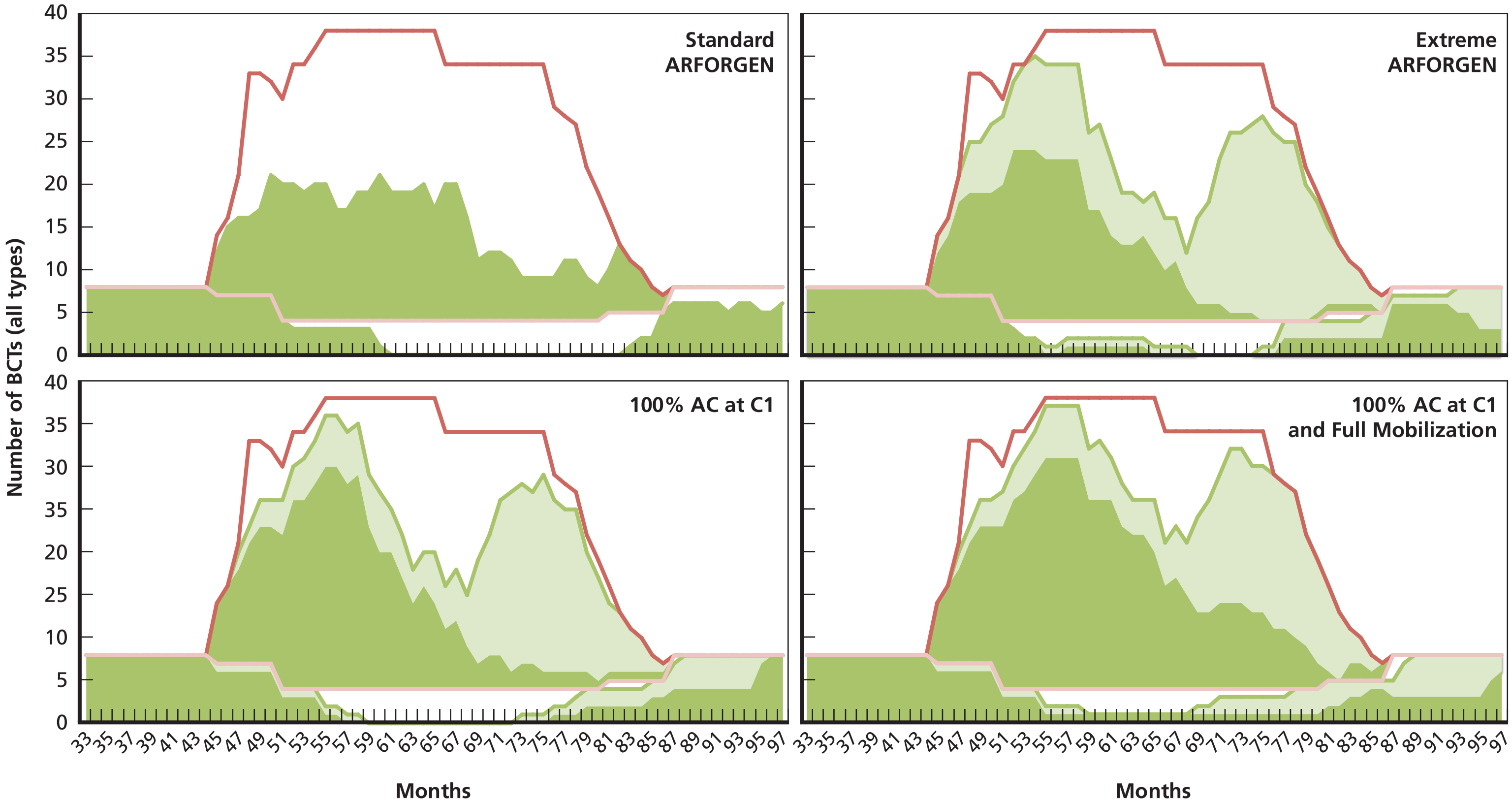
In order to simplify the graphic, all simulation configuration options not related to force generation policies are kept constant across runs. The four panels represent exactly the same overall demand signal across the same set of unit types (the three types of BCTs). The inventory (in terms of end strength and component mix) is kept constant. To simplify further, each figure includes only the time period of greatest interest, zooming in on the war period. Finally, the types of units used to fill demand are split only between more-ready (C1, dark green) and less-ready (C2, light green) units rather than providing splits by readiness level and component. We again make aesthetic improvements using red lines and "empty" space for missed demand.

In addition to exploring ability to meet demand, MPAFF outputs could also provide insights into the status of the undeployed force. Figure 4.11, for example, does not provide any information on the ability to meet demand. Instead, it lays out the deployment and readiness status of each of the 31 AC and 25 RC BCTs in the inventory. Red areas indicate deployed units (to both the steady-state and contingency scenarios), while green areas show the C-status of undeployed units. Darker green units are ready (C1), and lighter green units are less ready. We see that during and immediately following the war period, the number of available C1 units is very close to zero. Comparing this graph with Figure 4.3 confirms that periods with very low or no C1 undeployed inventory correspond to periods with missed demand.

Summary

The illustrative examples provided in this chapter show some of the ways in which MPAFF can provide quick-turn assessments to support capacity analysis. The main strengths of the Excel-based version of MPAFF are that it runs quickly (in a matter of

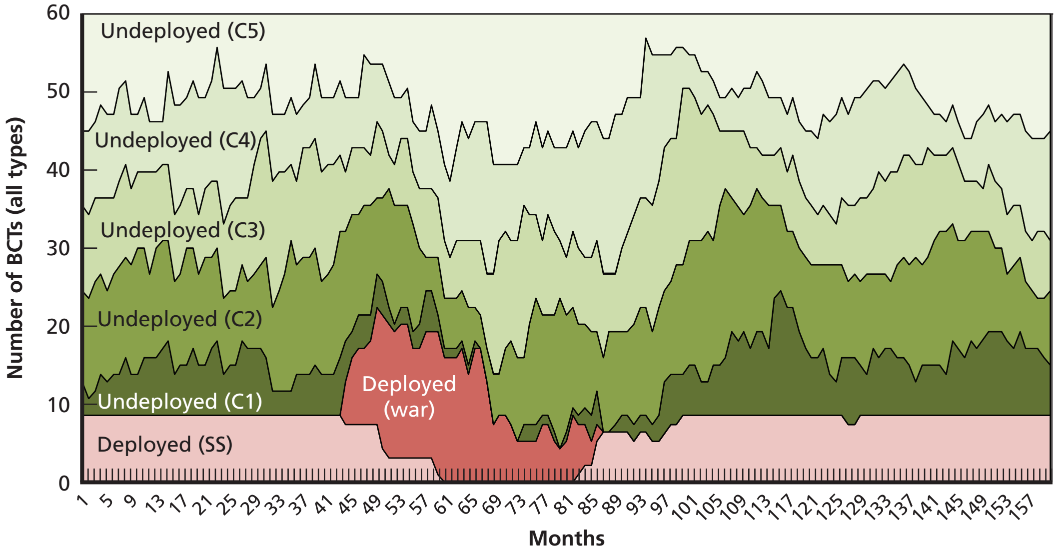
Figure 4.10
Customized Output Graph Highlighting Differences Between Force Generation Policies, All BCTs at 1,045,000 End Strength



NOTE: Four panels explore four different force generation policies. Red outlines indicate demand over time, and green shading indicates met demand. Darker green indicates demand met with ready (C1) units, while lighter green represents less-ready (C2) units.

RAND *RR1954-4.10*

Figure 4.11
Customized Output Graph Showing Readiness Levels of Undeployed Units, all BCTs at 1,045,000 End Strength



NOTE: Colored bands indicate status of units over time, with red indicating deployment and green indicating undeployed status.
RAND *RR1954-4.11*

seconds); allows for easy modification of inventory, demand, and policy inputs by users in real time; tracks time-phased performance over the duration of the desired simulation run; and generates results that can provide convincing visual representations of the analysis. While the force structures and demands used in this chapter are illustrative, the analysis can be easily performed on any other demands, force structures, or policies (whether authoritative or exploratory). Similarly, any readiness and force generation policies of interest can be explored. It is also equally easy to examine the effects of basic policy choices, such as extending forces during wartime, permitting selective disengagement from steady-state activities.

CHAPTER FIVE

Exploring a Larger State-Space with MPAFF-J

An Approach for Cross-Lever Data Analytics

The Excel-based MPAFF tool provides the opportunity to explore scenarios in detail. However, analysts may wish to examine how a wide array of policy options affects the ability to meet demand across many different scenarios. For example, analysts may wish to understand the ability to meet demand across a variety of different force sizes, scenario and steady-state demand signals, AC and RC mixes, and readiness models. Running more than a dozen options in Excel is illustrative but tedious without a way to run multiple configurations in a "batch" mode; the Java-based reimplementation introduced in this chapter allows analysts to run and examine thousands of policy lever configurations very quickly.

We wished to explore the range of possibilities across different policy levers. Strategies are defined by adjustments to policy levers over which decisionmakers have some control—such as the size and constitution of a future force or the planned level of peacetime readiness. Our goal was to enable the generation of data across a wider space-state, characterize the vulnerabilities of such strategies, and evaluate trade-offs among them. By generating the demand-met outcomes across combinations of strategies and scenarios, we can examine a wide range of plausible future demand scenarios and identify the strategies that allow the Army to meet these future demand goals. To distinguish this approach from the Excel model, we describe it as *cross-lever data analytics*.

In this chapter, we describe how we generated cross-lever data and explored the effect of a specific set of policy levers on the ability to meet demand under a variety of future demand signals. We focus on the same set of policy levers explored using the Excel-based tool, such as variations in force structure and component mix, readiness policies, and force generation.

However, we are able to explore a wider array of possible policies and combinations of policies. A combination of levers and scenarios creates one single run of the tool. An examination of all possible combinations for just ARFORGEN requires on the order of 250,000 runs. We focused on a subset of 13,000 of the most feasible combinations of levers.

To generate and examine the results from this number of runs, we developed a new tool called MPAFF-J. MPAFF-J uses much of the logic from the Excel-based MPAFF tool but is implemented in Java and allows for the generation, running, and examination of thousands of runs within several days. For example, generating 13,000 runs to examine the demand for one unit might take about half a day on a typical modern laptop. Output data from all runs are stored in a MySQL database, which allows them to be analyzed and examined in aggregate and queried to create required metrics and reports. Once MPAFF-J has generated the demand-met outcomes across the thousands of possible combinations, we are able to use a combination of visualization, statistical tools, and data analysis.

Unlike MPAFF, designed for interactive exploration of options by end-users, MPAFF-J is an analyst-oriented production tool relying on a complex suite of software tools (Java, MySQL, R, Tableau) that have to be integrated in specific ways. The runtime environment for MPAFF is not easily reproduced on standard Department of Defense information technology systems. Contact RAND if you have a specific question to explore using MPAFF-J, or if you are interested in more information about the precise software environment required for MPAFF-J.

MPAFF-J: Adapting MPAFF for Exploration of Levers Across Scenarios

There are several key differences between the MPAFF Excel tool and the MPAFF-J tool in terms of both functionality and implementation. MPAFF-J extends the functionality of MPAFF in a number of ways to support the systematic exploration of the space of input parameters (policy levers and demand signals) and the sensitivity of outputs to the various inputs. The primary functionality extensions are

- *generation of run configuration*: MPAFF-J has the capability to generate a variety of run configurations based on the policy levers and demand-signal options to be explored. Several text configuration files allow the user to specify the range of lever options and the set of supply and demand files to generate run configurations. MPAFF-J will then create the combinations of input files needed for each run.
- *multiple runs*: MPAFF-J has the capability to execute multiple runs based on a set of input files in a given directory. The input files can be configured by hand, if only a few need to be run, or generated combinatorially.
- *speed*: MPAFF-J completes each separate run in less than one second on most modern personal computers or laptops. This is significantly faster than the original, Excel-based MPAFF tool.
- *extensibility*: MPAFF-J is extensible and modular in regard to the force management model. The force management models explored in this report, such as

ARFORGEN and a sustained readiness model, are implemented in a modular way and could be replaced with different force management modules in the future. Each model is implemented in Java code and parameterized in the input configuration files. Theoretically, any set of rules that dictates the generation of readiness across time steps could be implemented as a force generation model.

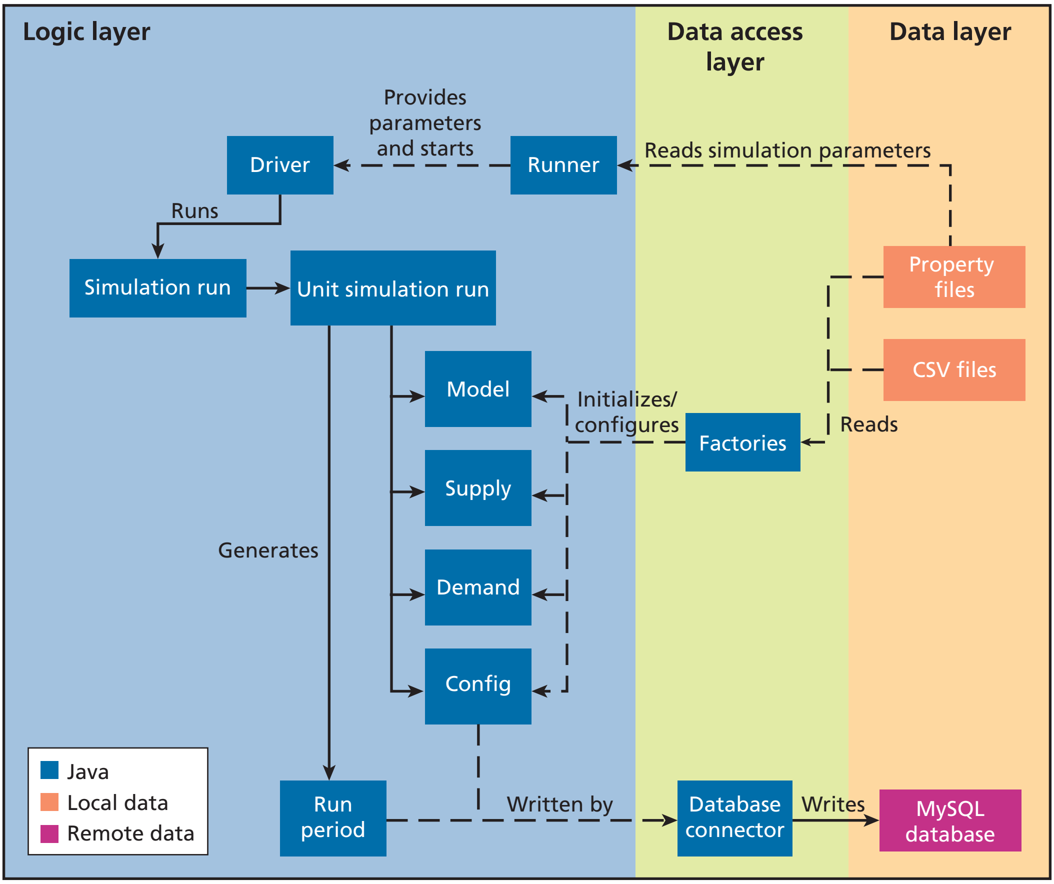
- *output data storage*: MPAFF-J stores the detailed results of each run in a MySQL database. This data storage supports a variety of comparisons of results across different runs, as well as the creation of customized summary statistics and metrics.

One significant functionality limitation of MPAFF-J is that *specialty software is required.* While MPAFF requires only Excel to run, MPAFF-J must be run on a machine with Java 1.8 or greater and MySQL installed and configured. Tableau and R (the computer language) are used for the data analysis after the runs have completed. MPAFF-J does not include an install script for these requirements, so these software components must be installed and configured manually. Figure 5.1 provides a visual overview of the various software components of MPAFF-J and how they come together to provide the overall capability.

Implementation differences between MPAFF-J and the Excel-based MPAFF tool stem primarily from the fact that MPAFF-J was developed in Java. As Java is an object-oriented programming language, we were able to design MPAFF-J from the ground up to use substitutable modules to increase reusability for future applications. This modularity allows us to easily incorporate alternative models (e.g., ARFORGEN, Sustained Readiness, or Tailored Readiness) for key processes, such as force generation, as needed. In particular, this will allow MPAFF-J to model such units as Patriot batteries, which have very different readiness, force generation, and deployment models. The primary implementation differences between MPAFF-J and the Excel-based MPAFF tool are

- *readiness distribution at start-up*: At start-up, both the Excel-based MPAFF tool and MPAFF-J attempt to assign units to readiness states in a way that evenly and proportionally distributes units across the appropriate training and readiness cycle. However, when dividing units across readiness states at start-up, MPAFF rounds down to a whole number of units; MPAFF-J instead rounds to the nearest whole number of units. As a result, MPAFF-J proportions units more evenly across readiness states when starting; due to the rounding differences, the Excel tool sometimes distributes slightly more units to the C2 phase at start-up.
- *demand tracking*: MPAFF-J keeps track of which war scenario or steady-state demand a particular unit is deployed to meet. This provides additional granularity for post-processing, because success or failure criteria can be tied to the type of demand or specific scenario. The Excel-based MPAFF tool tracks only whether a unit deploys to a war demand or a steady-state demand. In MPAFF-J, users can

Figure 5.1
Software Components of the MPAFF-J Architecture



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control prioritization across conflict zones through the order in which COCOMs are specified in the inputs. When scenario operations are under way in multiple COCOMs, the ordering in this list provides the ability to prioritize across locations, though not across specific individual scenarios. War scenario demands are filled before steady-state demands.

Force Management and Demand Levers

In this section, we describe the force management and demand levers that can be examined in the MPAFF-J tool. Force management levers are policy decisions that affect how many units are available and ready over time. Force management levers handled in the MPAFF-J tool include

- *force structure*: Any Army force structure of interest can be represented in MPAFF-J, where force structure is defined by a number of units in each component for each unit type. Different force structures could be used to explore the effect of various end strengths, capabilities mixes, and component mixes.
- *force employment*: The MPAFF-J tool has options to control whether AC and/or RC units can be used to satisfy demands. The tool also has options to control whether units have to achieve C1 or only C2 readiness status prior to deployment. This option can be set separately for AC and RC units. Force employment rules can be set separately for each unit type and can differ across the various wartime scenarios included in a given model run.
- *readiness models*: MPAFF-J currently implements two major readiness models, ARFORGEN and Sustained Readiness. Within each of these broad models, MPAFF-J has additional parameters that tweak readiness and force generation for each unit type. For example, users can control the delay in deploying the first RC units (we examined delays of three, six, and nine months after the start of a war scenario, but other values can be used). When an ARFORGEN readiness model is used, MPAFF-J also allows setting the BOG:Dwell ratio separately for each unit type, component, and phase of the conflict (peacetime, wartime, and surge). In a Sustained Readiness model, users can set parameters to control the sizes of different readiness tiers, deployment lengths, and the rate at which units can build readiness.
- *deployment length/extensions*: The tool allows for exploration of deployment extensions, by providing options for setting maximum deployment lengths for both AC and RC, including an "indefinite" option in which units deployed to a war remain deployed until the war ends.

Demand levers allow users to create a variety of demand signals over time by stacking the scenario and steady-state demands. Different configurations of these underlying demand-signal building blocks represent a variety of potential future demands for Army forces. Demand levers handled in the MPAFF-J tool include

- *steady-state demand*: In MPAFF-J, steady-state demand for each unit type can be set on a per-COCOM basis. Steady-state demands are generally deployed rotationally, but individual demands can also require a "home-stationed forward" unit, as explained in Chapter Three. Some or all of the steady-state demand can be designated as available to meet wartime scenario demands in that COCOM's area of responsibility (or not). Similarly, some or all of the steady-state demand can be designated as "optional" if there is a war in another COCOM; this option provides a mechanism to model disengagement from the "rest" of the world during wartime. The illustrative model runs presented here experiment with six different levels of steady-state demand. Demand signals vary in size (low to high) and in their preference for rotational versus home-stationed forward deployments.

- *scenario demands*: Scenario demands capture demands for forces in potential future conflicts. The illustrative work uses longer and shorter scenarios in each of two COCOMs, USPACOM and USEUCOM, for a total of four major contingency scenarios. We explore various combinations of these scenarios, as well as several options for relative timing (simultaneous versus lagged conflicts). MPAFF-J allows complete control over which scenarios are included and excluded, as well as over the start time for each scenario.

Demonstration of the MPAFF-J Tool

In this section, we present a number of illustrative simulations to test and demonstrate MPAFF-J and the kinds of analysis that users can perform with it. Each simulation is defined by one permutation of the force management parameters and demand scenario combinations. Table 5.1 shows the various parameters and specific parameter values used for this demonstration. This set of parameters and values results in 248,832 unique simulation configurations, which form the basis of the illustrative outputs shown in the next section. We focused on a subset of 13,000 of the most feasible combinations of levers. Furthermore, all examples in this chapter are based on the ARFORGEN model, but Sustained Readiness is also implemented in MPAFF-J, and the modular design allows other models to be added.

In Table 5.1, various force management parameters have been collected into three overall options that we have called *standard*, *medium*, and *extreme* force management options. These could all have been explored individually, but they form a set of parameters that generally have associate values and are more easily understood and presented collectively. These force management options and their specific parameter values are shown in Table 5.2.

Interpreting MPAFF-J Outputs: Aggregate Success Metrics for Cross-Lever Data Analytics

To interpret results across the large number of runs made possible by MPAFF-J, we must develop output metrics that can explain how success and failure are distributed across the state-space of parameter input values. One option is to create a binary metric that categorizes each individual simulation run as either a success or a failure. To create such a metric, we seek a way to aggregate the monthly counts of met and missed demands, across all scenarios, into a single success metric. We additionally explore scenario-specific metrics, which we describe at the end of this chapter.

Table 5.1
Parameters and Parameter Values Used in the Demonstration of MPAFF-J

	Parameter	Specific Parameter Values
Force size and mix	Force structure	Individual unit inventories corresponding to 3 Army end strength options: • 1,045K (comprising 490/350/205K for the AC/ National Guard/Army Reserves) • 980K (450/335/195K) • 910K (420/315/175K)
Risk/allowable mission	RC C1 use	• on • off
	RC C2 use	• on • off
	AC C1 use	• always on
	AC C2 use	• on • off
Readiness models	RC delay	• 3 months
	Force management	Three force management options are explored: • standard • medium • extreme These options are defined by individual parameters as explained in Table 5.2.
	Deployment length baseline	Baseline deployment length is 9 months for both AC and RC.
Steady-state demand	Steady-state demand level	6 total options; for each of these 3 (baseline, high levels, low levels), we have a home-stationed and a rotational leaning version.
	Ability to disengage	• Allow all steady-state units to become optional during wartime and deploy to a war in the same COCOM • Do not allow
Scenario demands	Scenario start, end, length, and location	16 combinations comprising four key contingency scenarios: • 2 USPACOM scenarios starting in month 45 • 2 USEUCOM scenarios (short and long) with start month options of 40 (near-simultaneous, before PACOM), 45 (simultaneous), 48 (near-simultaneous, after PACOM), and 72 (no simultaneity)

NOTE: The MPAFF-J tool used these parameters to create 248,832 unique simulations. K = thousand.

We initially examined the following metrics to understand variability across simulations. Employing several different metrics allows us to understand how the definition of success affects interpretation of results:

- *the percentage of total demand met.* How much demand, both steady state and scenario, was met across all periods? The calculation for each simulation is (sum over

Table 5.2
Parameters and Parameter Values for Force Management Options Used in the Demonstration of MPAFF-J

	Parameter	Specific Parameter Values
Standard force management	AC wartime deployment length	12 months
	AC BOG:Dwell	1:3 peacetime, 1:3 wartime
	RC BOG:Dwell	1:5 peacetime, 1:5 wartime
Medium force management	AC wartime deployment length	12 months
	AC BOG:Dwell	1:3 peacetime, 1:2 wartime
	RC BOG:Dwell	1:5 peacetime, 1:5 wartime
Extreme force management	AC wartime deployment length	18 months
	AC BOG:Dwell	1:3 peacetime, 1:1 wartime
	RC BOG:Dwell	1:5 peacetime, 1:4 wartime

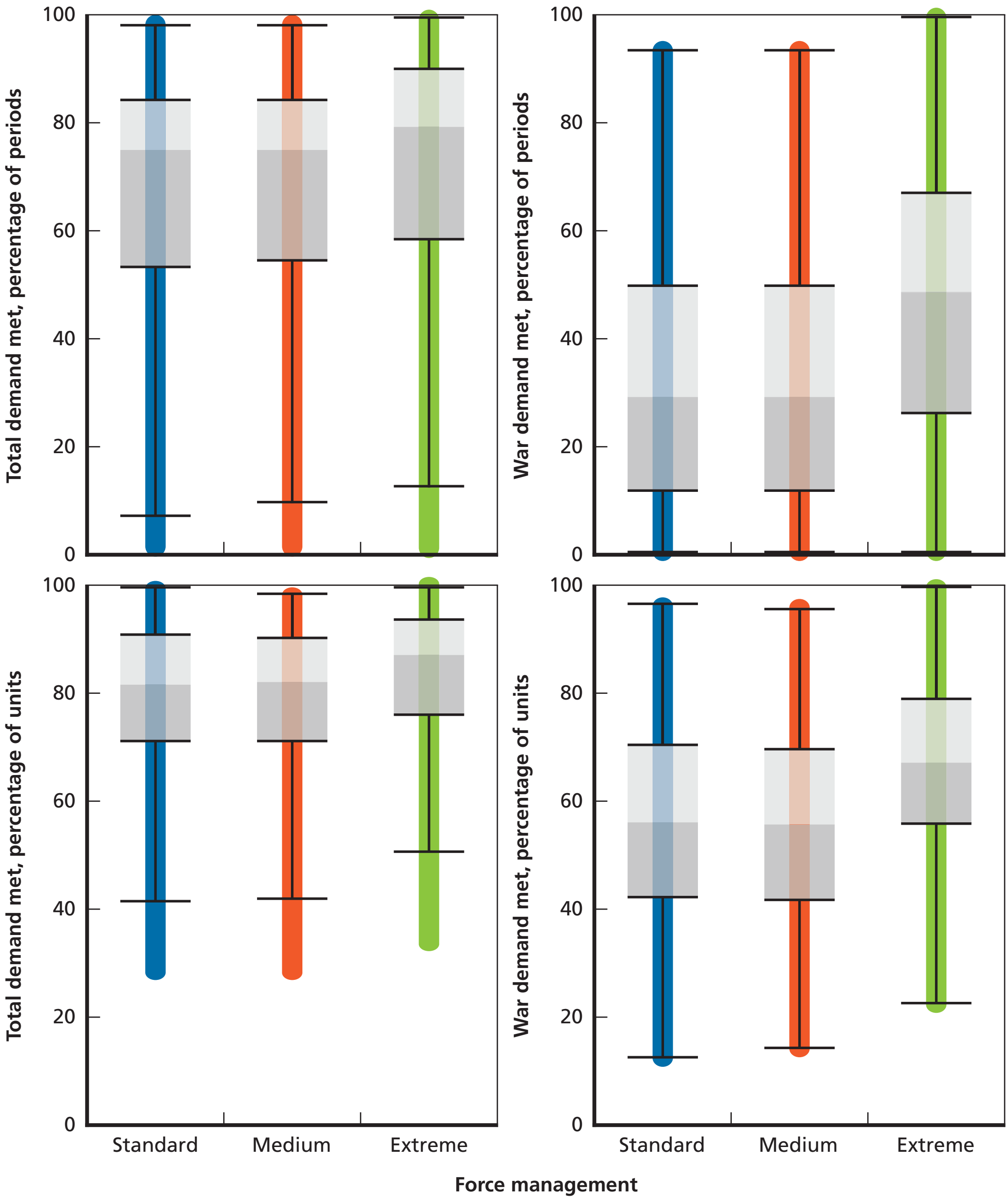
NOTE: RC deployment length is held constant at nine months. A three-month mobilization period is assumed for BCTs prior to deployment.

all periods of the number units deployed) / (sum over all periods of the number of units demanded).

- *the percentage of scenario demand met*. Similar to previous but looks at only scenario demand and scenario deployment. The calculation for each simulation is (sum over all periods of the number of units deployed to a scenario) / (sum over all periods of the number of units demanded across scenarios).
- *the percentage of periods in which the total demand for that period was met.* For each period, we looked at whether total demand for steady state and scenarios was met. We then calculated the percentage of periods that met demand in that simulation. The calculation for this metric is (number of periods with demand completely met) / (number of periods).
- *the percentage of periods in which the scenario demand for that period was met.* Similar to previous but for scenario demand and deployment only. For each period, we looked at whether total scenario demand was met. The calculation for this metric is (number of periods with scenario demand completely met) / (number of periods).

Figure 5.2 highlights some of the differences between these metrics. These box plots compare performance across different force management options using each of the four metrics. The individual dots (which often overlap, merging into a thick line) on these plots each represent the result of a run based on a single permutation of the

Figure 5.2
Comparison of Four Different Metrics of Demand Met



NOTE: The total demand met metrics paint rosier pictures than war demand met, as steady-state demand is often met. See Table 5.2 for details on standard, medium, and extreme force management.
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input parameters (what we refer to as a *simulation*). The placement of each dot on the y-axis indicates how successful that simulation was under the current success metric. The top two plots compute the percentage of periods in which demands were met (all demands on the left, war demands only on the right). The bottom two plots compute the percentage of demand met (again, all demands on the left, war demands only on the right). In each quadrant, the results are further subdivided according to the force management policies in effect (these are discussed in Chapter Four), which have been categorized as *standard force management policies, medium force management, and extreme force management* (see Figure 5.2 for details of these policies). In all four quadrants, the plots for standard and medium force management look almost the same, and only for extreme force management is there any significant difference observable. This is consistent across both metrics, indicating that medium force management policies are not enough to significantly improve the ability of BCTs to meet demands; instead, extreme force management policies are required to appreciably improve the ability of BCTs to meet demands. The box plots illustrate both the center of mass and spread of values. The centerline of each box plot represents the median value across that sample. The top and bottom of each box are the first and third quartile of the sample. The "whiskers" or "antennas" represent 1.5 times the interquartile range (IQR);[1] values (dots) beyond the whiskers are considered outliers.

Figure 5.2 highlights some differences between the metrics. Looking at total demands (left column of Figure 5.2) tends to paint a better picture across all force management options than looking at war demand (right column), whether we look at met demand by percentage of units (bottom row) or the sum across all periods (top row). This is due to the high likelihood of meeting steady-state demands in periods when there are no ongoing contingencies and total demand is low. There is slightly different information contained in the percentage of periods with total demand met and the percentage of demand met across all periods. The top right in Figure 5.2 shows that in the worst case, there are simulations in which no period with war demand was able to fully meet that war demand. However, even the worst simulation met 12 percent of war demand for units across the entire run, as shown in the bottom right. However, this does not tell us how much was missed in any particular period.

The traditional RDM approach goes one step further in creating aggregate success metrics, requiring a binary metric of either success or failure for each simulation. This type of metric allows us to examine how many simulations succeed and where in the state-space of parameter options success is most likely. One example of a binary metric is, "Did deployments always meet at least 50 percent of war?" Figure 5.3 shows how many scenarios succeeded or failed using this metric. In this case, we see that most

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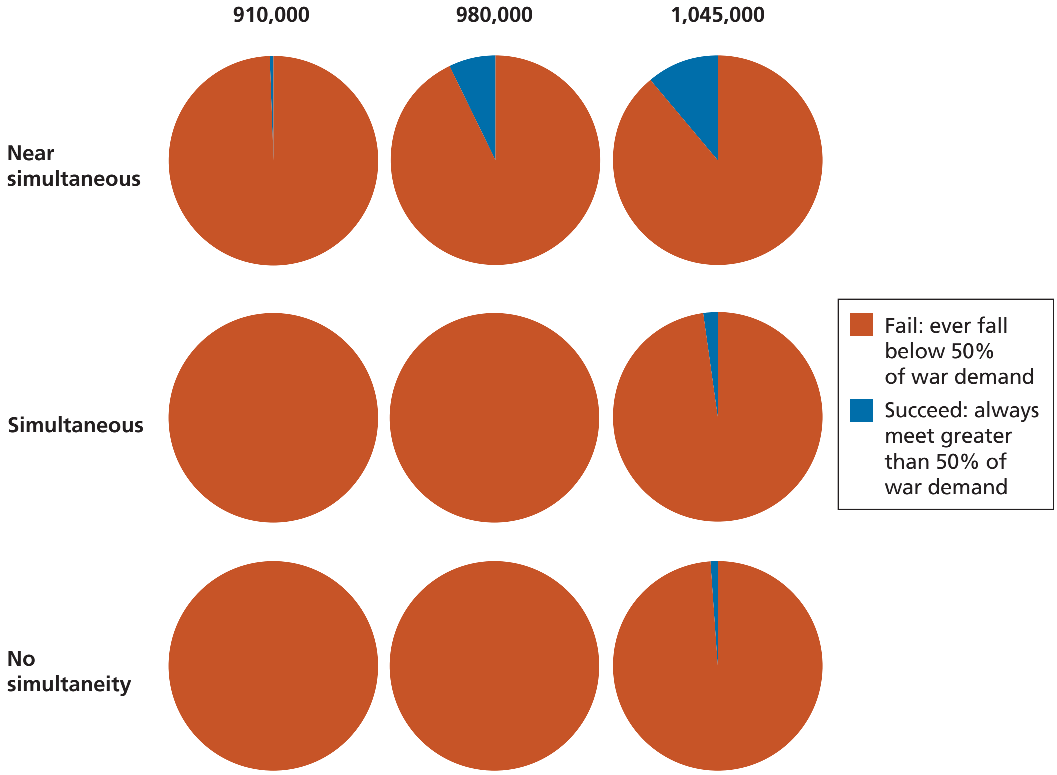
1 The box plots show the lower and upper quartile within the boxes. The lower quartile is the median of the lower half of the data, and the third quartile is the median of the upper half of the data. The distance from the lower quartile to the upper quartile is the IQR. The whiskers represent the distance from –1.5 times the IQR to 1.5 times the IQR. Outliers not representative of the data set may fall above or below the whiskers.

Figure 5.3
Number of Cases in Which at Least 50 Percent of the Demand Was Always Met



NOTE: Near simultaneous = USEUCOM starting at month 40 or month 48. Simultaneous = USEUCOM starting at month 45. No simultaneity = USEUCOM starting at month 72.
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scenarios failed, although there were more instances of a successful outcome in the simulations using larger force size. Due to the strict, binary definition of success, the sliver of success is small enough that this metric is not very helpful in differentiating the useful levers. However, it may be a useful metric for highlighting the inherent risk in the particular force structures we experimented with.

The metrics described above and shown in Figures 5.2 and 5.3 provide aggregate metrics across the entire period examined. These metrics are not tied to any specific scenario or based on strategic understanding of what success and failure look like for a particular scenario. Options for scenario-specific metrics are discussed in the next section.

Scenario-Specific Success Metrics

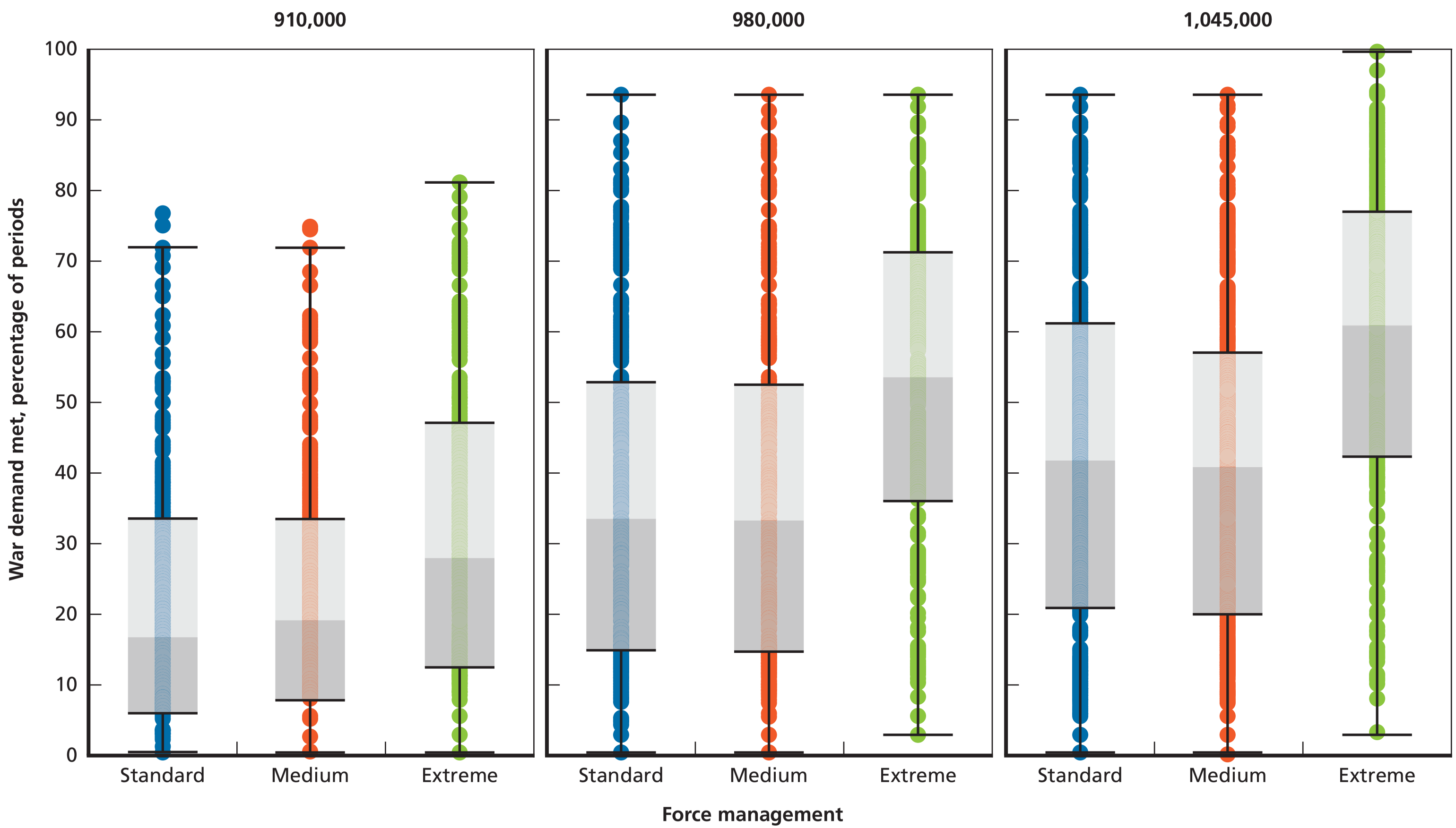
While the aggregate metrics described above can be useful, they do not reflect specific operational risks for any particular scenario. For example, the key operational risk for a war in USEUCOM may be meeting the full demand within the first few months of the war. A potential war in USPACOM may have different criteria for operational risk. This type of expert knowledge can be incorporated into MPAFF-J runs by creating customized success metrics that take strategic considerations into account. We can attempt to establish metrics that capture different possible types of operational failures, such as an inability to defend when attacked, the need for a delayed counteroffensive, or a situation where forces are entirely insufficient for an effective counteroffensive. For example, in a USPACOM scenario, we could assume that a defense may fail or a counteroffensive needs to be delayed if less than 70 percent of scenario-specific demand is met during the first three months of the war. In a USEUCOM scenario, success may require 85 percent of scenario-specific demand met in the first month and 80 percent of scenario-specific demand met in the second and third months. Other metrics may look at the long-term sustainability of a war. For example, if a specific scenario's demands are not met for more than three consecutive months, this may affect the ability to stabilize the war zone and the ability to deter and provide security. Alternatively, the inability to meet steady-state demand in certain critical regions may signify failure. These are all potential metrics that can be applied to the MPAFF-J output to understand success and failure in scenario-specific ways.

Sample Visualizations to Support Analysis of Levers

To illustrate the type of data exploration and analysis available when examining a large set of possible scenarios and levers, we focus on just one of the metrics defined above: *the percentage of periods in which the war demand for that period was fully met.* We recognize that this is an imperfect metric, but it serves to illustrate the kinds of analyses that we can perform on the MPAFF-J outputs. MPAFF-J enables its users to explore the successes and failures of varying force management parameters and demand scenario combinations visually.

Visualizations are a helpful tool for understanding the impact that various policy levers have on ability to meet demand. The following examples provide a small sample of the many different visualizations of our illustrative output data that could be used for exploration. Figure 5.4 and Figure 5.5 present two visualizations showing how both force management decisions and force size affect the scenario demand met. These figures summarize the same data in two different ways: boxplots in Figure 5.4 and pie charts in Figure 5.5. Figure 5.4 plots the ability to meet demand (measured by the percentage of periods during which all scenario demand is met, vertical axis), broken out by force size and force management policy used. Each of the three panels represents a force size. Each panel includes three color-coded boxplots, one for each force management option. The boxplots show a high level of variance for all force management options. This implies that choices about force management and force size alone cannot guarantee success; within our current boundaries of possible force sizes and force management options and given our illustrative demand signals, there are always possible

Figure 5.4
Boxplot Representation of How Many Scenarios Met Most War Demand



NOTE: See Table 5.2 for details on standard, medium, and extreme force management.

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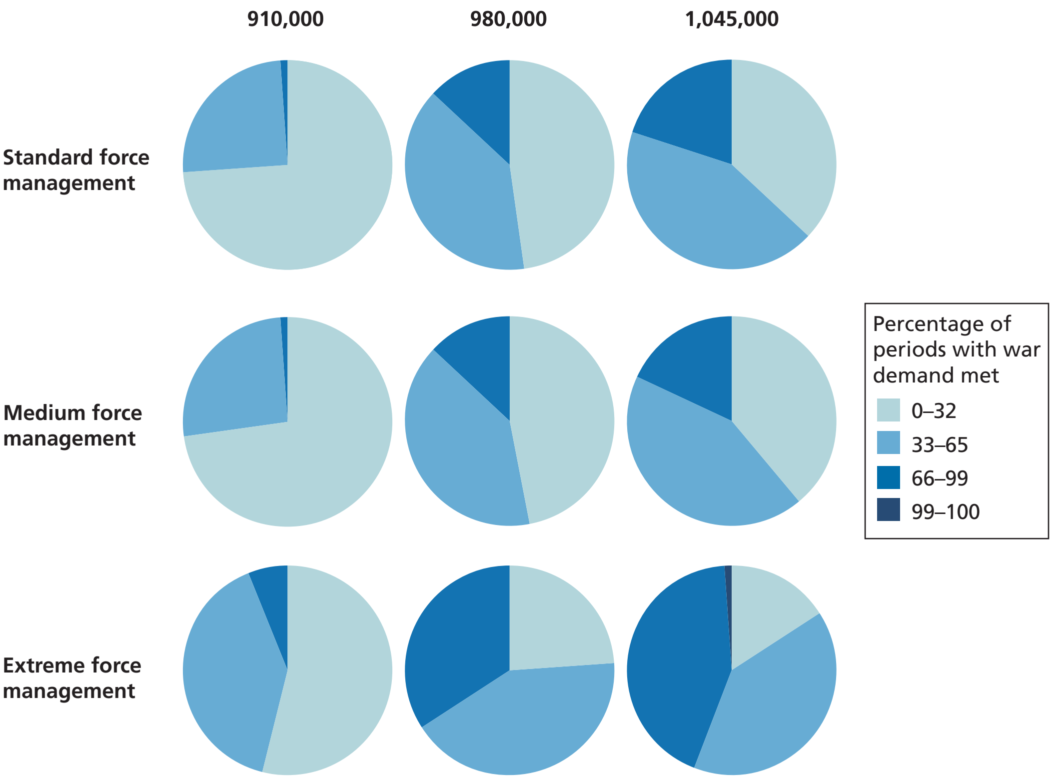
Figure 5.5
Pie Chart Representation of How Many Scenarios Met Most War Demand



NOTE: See Table 5.2 for details on standard, medium, and extreme force management.
RAND *RR1954-5.5*

future war demands for which the Army likely cannot provide the requested number of ready forces.

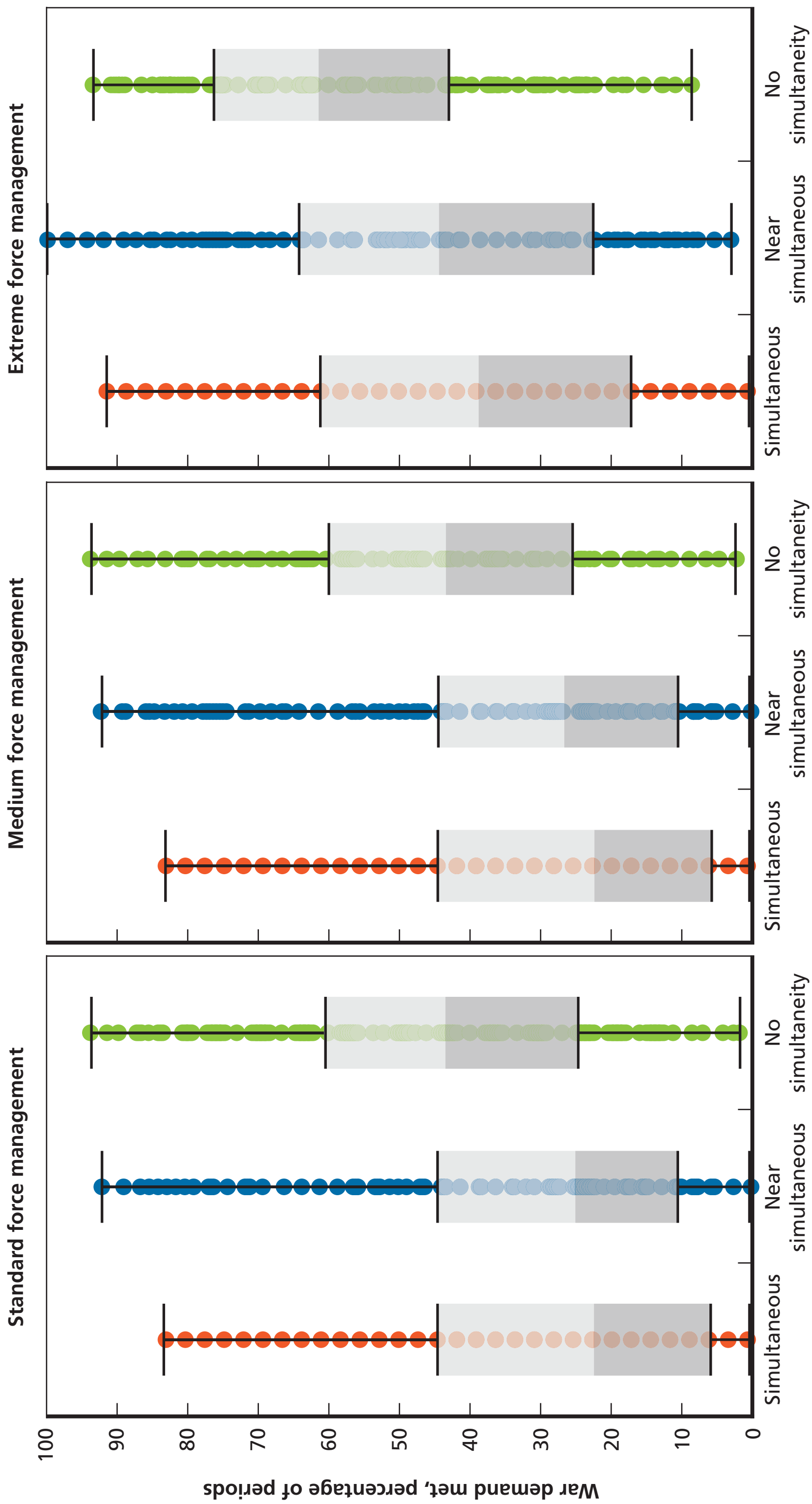
Figure 5.5 presents the same data using pie charts; each pie chart represents a combination of force management option and force size, with force size varying as we move left to right and force management option varying as we move from top to bottom. The success metric (percentage of periods with met scenario demand) is binned into categories of < 33 percent, 33–66 percent, 66–99 percent, and > 99 percent of periods with met demand. The color-coding in each pie chart shows how many of the simulations with the given configuration of force size and force management fall into each bin. The pie charts in Figure 5.5 also show (as expected) that larger force sizes under extreme force management consistently meet war demand in more periods than smaller forces under less extreme force management. Darker shades of blue represent a higher proportion of met war demands. The slices of darker blue grow as we move downward and to the right. We also see that the move from standard to medium force management has little effect, while a shift to extreme force management brings a significant improvement in the overall ability of the force to meet war demands.

We can use vizualization to study the effect of levers other than force management policies and force size. In Figure 5.6, we examine how the timing of scenarios (simultaneous, near-simultaneous, no simultaneity) can impact the amount of scenario demand met with different force management options. Figure 5.6 shows the ability to meet demand (measured by the percentage of periods during which all scenario demand is met, vertical axis), broken out by force size (management type) and scenario timing. Each of the three panels represents a force size. Each panel includes three color-coded boxplots, one for each scenario timing option. From Figure 5.6, we can conclude that there is not much difference in scenario demand met between simultaneous conflict starts and the cases when two conflicts start a few months apart. Ability to meet demand is improved in simulations where the two scenarios do not overlap; however, even in the nonsimultaneous, one-war-at-time cases, there is a large spread in the percentage of periods during which scenario demand is met. Some runs with no simultaneity and extreme force management still result in fully met scenario demands in only about 10 percent of model periods.

These sorts of visualizations can help uncover counterintuitive results, which may merit further investigation. For example, Figure 5.7 breaks down the same metric of ability to meet demand (percentage of periods during with all scenario demand is met, vertical axis) by force management option amd size of the USEUCOM and USPACOM scenarios. This figure consists of three vertically stacked panels, one for each force management option. Within each of these three panels, there are four boxplots representing four possible scenario combinations for the major combat operations included in this model run. The four combinations are (1) a longer USPACOM scenario and a longer USEUCOM scenario, (2) a longer USPACOM scenario and shorter USEUCOM scenario, (3) a shorter USPACOM scenario and longer USEUCOM scenario, and (4) a shorter USPACOM scenario and shorter USEUCOM scenario. The first boxplot in each panel (reading left to right) includes simulations with a long USPACOM and long USEUCOM scenario, while the second boxplot includes simulations with a long USPACOM and short USEUCOM scenario. The third boxplot includes a short USPACOM and a long USEUCOM scenario, while the fourth and final boxplot in each panel includes a short USPACOM and a short USEUCOM scenario.

From these plots, we see that when there is a shorter USPACOM war scenario, simulations with the shorter USEUCOM scenario have less met demand than simulations with the longer USEUCOM scenario. This appears to hold across all force sizes. This is surprising, as one might expect that it would be easier to meet demand in the shorter scenario. However, our metrics are based on a percentage of total periods with unmet war demand. The inclusion of a longer USEUCOM scenario leads to more periods within the simulation run being included in the calculation of our metric. The

Figure 5.6
Effect of Relative Scenario Timing on the Ability to Meet Scenario Demand



NOTE: See Table 5.2 for details on standard, medium, and extreme force management.

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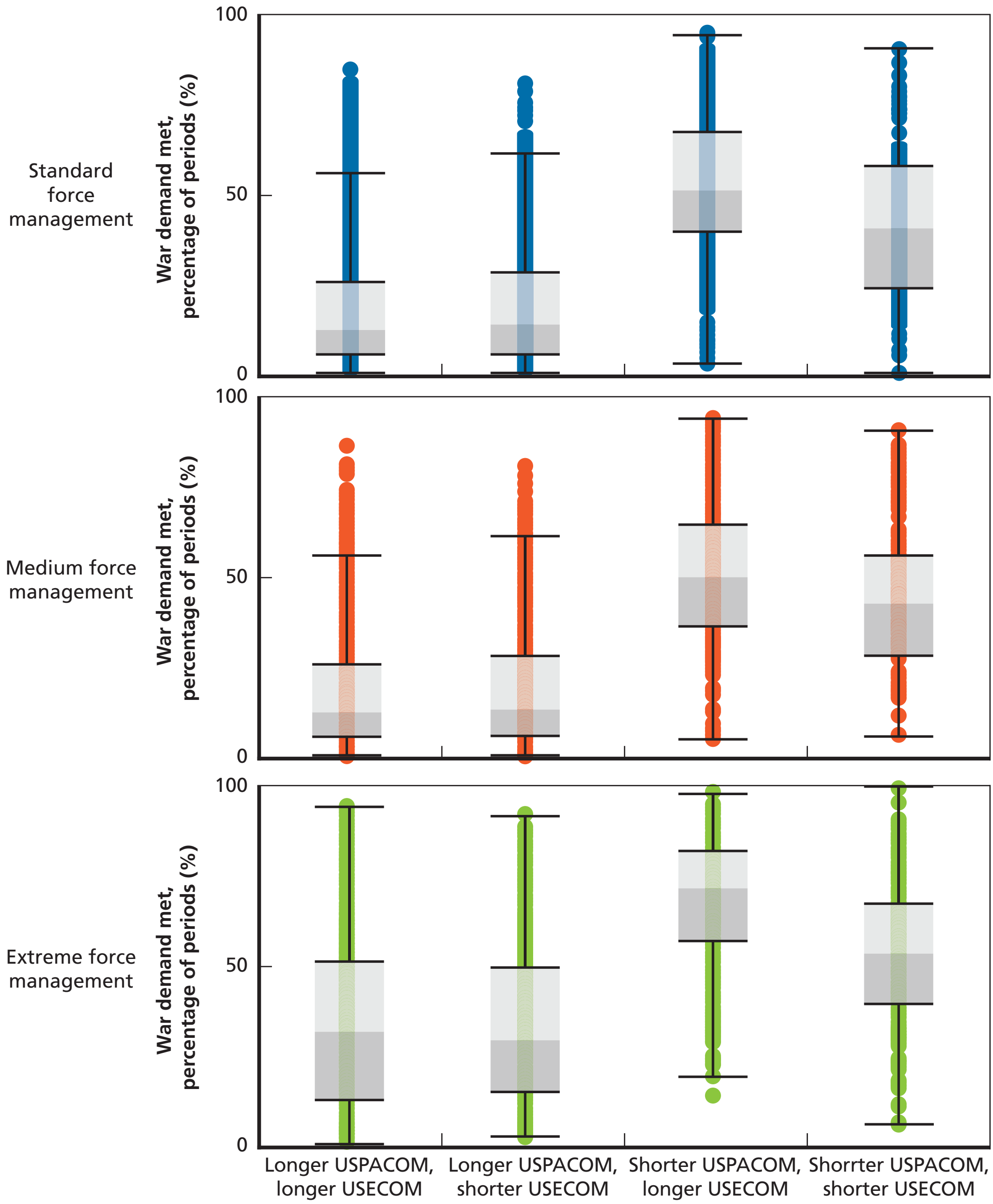
Figure 5.7
Effect of Short Versus Long War Scenarios on the Ability to Meet Scenario Demands



NOTE: See Table 5.2 for details on standard, medium, and extreme force management.

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demand in the long tail of the longer scenario is smaller than the initial peak demand at the start of the war, so demand in this larger number of later periods is more likely to be met. The few periods at the beginning of the war with unmet demand have more of an impact on our success metric when a shorter USEUCOM scenario is included in a run.

There are multiple options for examining the data produced by MPAFF-J. In Figure 5.8, we show that the analysis can be performed on multiple units. While the previous figures were demonstrating the metrics for only infantry BCT, it is possible to include multiple units. The demand met for each unit can be analyzed separately, as seen in Figure 5.8, where infantry BCT appears to miss marginally more war demand. For alternative analysis across scenarios, the performance across all units can be averaged or summed; the appropriate analysis may depend on the specific question being examined.

In Figure 5.9, we demonstrate the use of a scenario-dependent metric. In this example, we are looking only at cases that include the longer USEUCOM scenario. We develop a scenario-dependent binary metric of success; we define the cases as failing if demand met (in number of units) for the USEUCOM war drops below 70 percent at any time during the first three months of the EUCOM war scenario. One of the challenges of the USEUCOM war scenario is the requirement for a large number of initial forces in early days and months to prevent a *fait accompli*. The specific success metric shown in Figure 5.9 was designed to illustrate one way of capturing those cases

Figure 5.8
Difference in Total Missed Demand and War Missed Demand Across Three Units with Different Supply and Demand Specifications

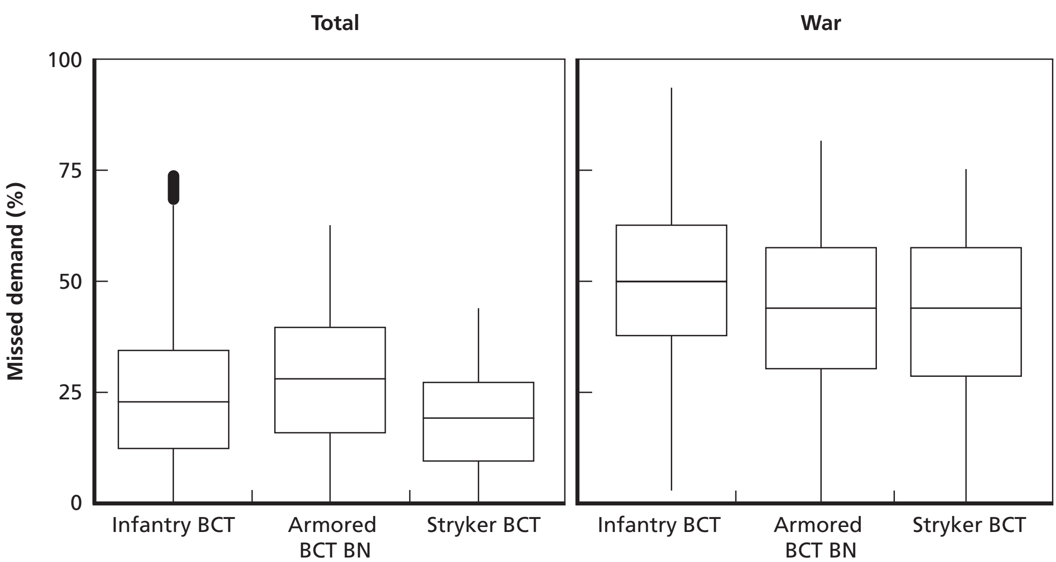

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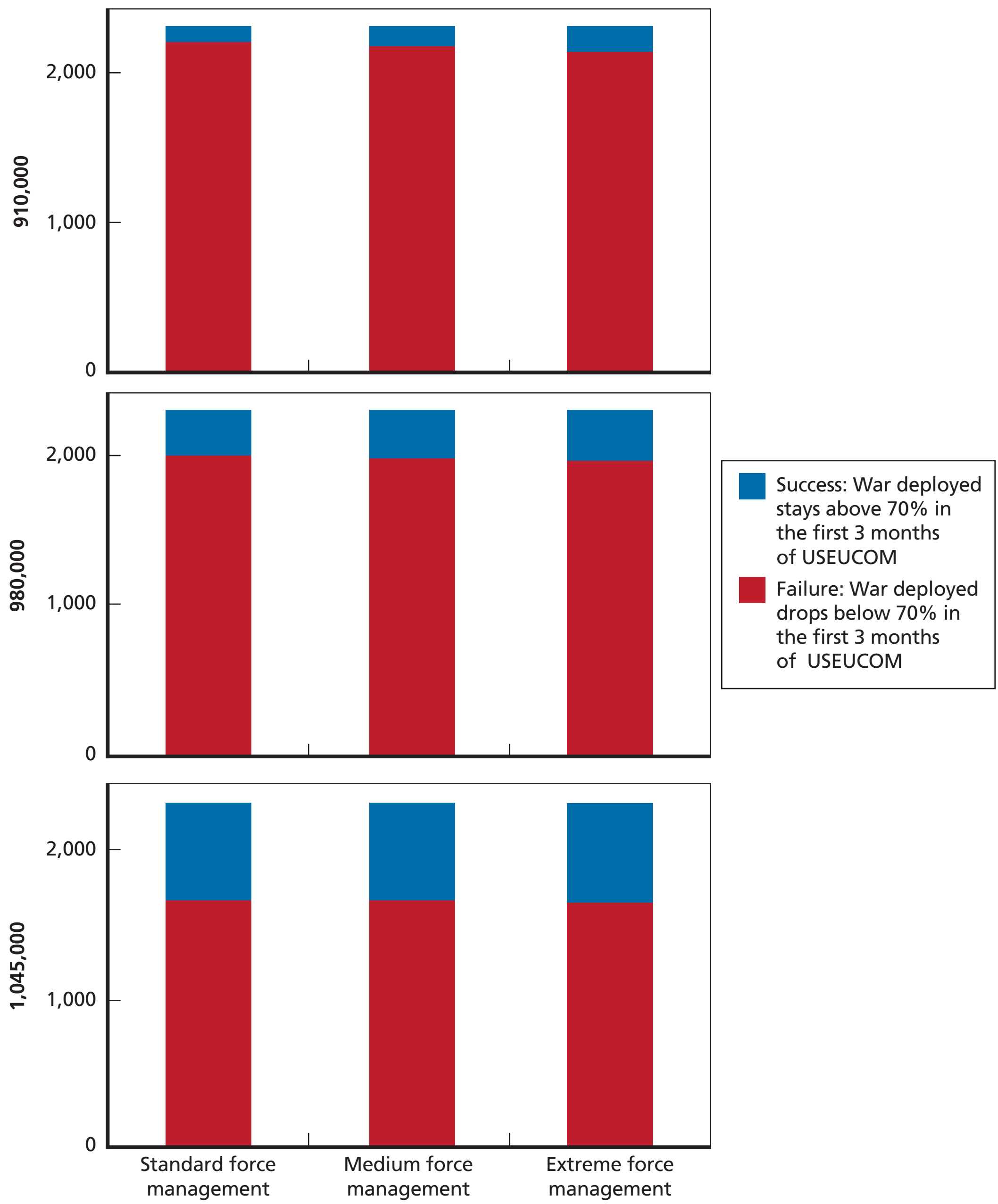
Figure 5.9
Example of a Scenario-Specific Metric Focused on the Initial Demand for Forces in the USEUCOM Long Scenario



RAND *RR1954-5.9*

that succeed in providing sufficient forces during the crucial first three months. This binary metric specifically looks at the met demand in USEUCOM at the beginning of the surge; this does not—by design—include met demand in other locations in the metric. It is not surprising that changes in force management policies do not significantly affect the results. This metric focuses exclusively on the ability to surge forces; force management policies primarily affect the ability of the Army to sustain forces over the length of the scenario.

This simple example demonstrates the ability to define location-specific metrics and how they can provide further insights into issues of interest. Tailored, scenario-specific metrics like the one described here can be developed to answer a variety of specific questions that policymakers might have. For example, scenario-specific metrics could focus on the beginning, middle, or end of a contingency; prioritize success in certain geographies; or capture the worst or best performance across the whole period of the simulation run.

In summary, the MPAFF-J tool allows us to examine force sufficiency results across a large number of combinations of force management and demand-signal levers. This chapter portrayed sample analysis of the results from an illustrative MPAFF-J run. MPAFF-J allowed us to generate a complete data set of results across these many configurations. From the raw result data, we were able to define customized success metrics to study specific policy questions of interest. We then created visualizations to help understand the impact of different policy levers (including force management, force size, scenario simultaneity, and length of scenarios) on these metrics. These examples are only illustrative and need to be confirmed with further analysis (including analysis based on classified demand signals and scenarios). The work presented here serves to illustrate the power of this tool and methodology.

CHAPTER SIX

Conclusion

The tools RAND has developed, MPAFF and MPAFF-J, provide the ability to explore the capacity of the operational force structure and force generation to meet a variety of peacetime and wartime demands. These tools also help us understand the effect various policy levers and force management factors have on the ability to meet demand. Because these tools are quick to run, they provide the ability to perform timely quantitative assessments of capacity relative to future demand under a variety of force structure and force management policies—a capability not currently provided by other tools available to the Army. These tools connect changes in force structure, readiness processes, force management polices, and force deployment policies to changes in the operational risk incurred in strategically significant scenarios. This enables analysts to provide the kinds of inputs to decisionmakers necessary for informed assessments of the relative risks and consequences of different options.

The MPAFF tool provides a user-friendly interface that enables quick and easy interactive exploration of a particular set of options and assumptions. In contrast, the MPAFF-J tool is designed to enable systematic exploration of the decision space across a broad set of options and assumptions, allowing for sensitivity analysis of the effect of a variety of policy options and combinations of policy options. In combination, the tools support

- assessment of the overall risk of Army force structure across national strategic requirements
- exploratory development of potential policy options for the Army
- in-depth analysis of selected policy options to understand the full range of risks, their robustness across a variety of possible future environments, and sensitivity analysis with respect to assumptions.

The representative examples of MPAFF analysis illustrate how the tool can be used to assess how various proposed Army force structures perform in addressing potential two-war scenarios involving major power conflicts and near-peer adversaries. Similarly, the illustrative examples of MPAFF-J analyses show the tool can be used to inform debates concerning the effect that varying the separation between two wars (do they start simultaneously, or offset by three months, six months, nine months, etc.?) may have on the ability of the Army to meet the aggregate demands. These illustrative results demonstrate the potential these tools have to inform debates at senior levels.

APPENDIX A

User Guide for Excel-Based MPAFF Tool

This user guide expands on the conceptual tool description found in Chapter Three to provide practical instructions for running the MPAFF tool. Users interested in making modifications to the underlying code for the purposes of, for example, adding readiness models or changing the types of stored outputs may need additional developer support and should contact Katharina Best (katharina_best@rand.org).

Quick Start

A current version of the MPAFF tool is available to Army users from the RAND Corporation's Arroyo Center. The tool comes prepopulated with sample data and illustrative values for all necessary simulation parameters. To run this illustrative sample tool, users must open the Excel file, enable macros for this workbook, and click the "Run model" button at the bottom of the *Inputs* worksheet. This will run MPAFF with prepopulated sample data and take users to the *Outputs* worksheet. To view sample output, users should select units for which they would like to see outputs and click on the "Generate output plots" button. The rest of this chapter explains how users can manipulate simulation inputs to execute further runs that may be of interest.

Basic Tool Components

The basic simulation components of the MPAFF tool include demand data of two types, supply data, and the force generation and readiness rules that allow for period-by-period simulations. Supplies, demands, and rules that govern the generation of ready units over time are generally specified for each unit type included in the simulation run.

- **Unit types and number of units (supply):** Each unit type represents a type of force element to be included in the run. For each unit type, supply is specified by the number of individual units of that type available in the force structure. For example, you may have an "Infantry BCT" unit type and specify the existence of eight "Infantry BCTs" in the supply section of the tool. Unit types may be specified at any level, from a whole division all the way down to an individual soldier, so long as demand and supply are specified at the same level for each unit type and readiness behavior across periods can be defined at that level. This level need not be consistent across different unit types within a run: A run can simultaneously contain infantry BCTs and engineering companies.

- **Steady-state demand:** The steady-state set of inputs to the tool specifies the expected demand for units in a nonwar environment. These steady-state demands are simplified and represented as a constant demand across all periods, though slight adjustments can be made to these demands in the event of scenario demands. These adjustments are described later in this appendix.[1]
- **Scenario demands:** Scenarios represent demands above and beyond steady-state activities. Each scenario represents operations in a single COCOM, and demands are specified over time, each period. Scenario demands cover both surge and sustainment operations.[2] The "surge" portion of a given scenario may be as long as the scenario itself or as short as a single period. Users can select and schedule scenarios for each run and control various tool behaviors for the surge period specifically. For example, deployment extensions may be allowed during wartime, and the requirement for steady-state presence may be reduced. MPAFF also gives users the ability to control force management rules, such as readiness rotation speeds, for the surge and sustainment portions of each scenario separately.
- **Readiness/force generation rules and period-based simulation:** The MPAFF tool approximates time by discrete periods. Readiness models specify how units of a particular type move through readiness levels as time progresses, period to period. The readiness model and associated parameters can be set for each unit type. Two key types of readiness models are already included in the MPAFF tool (one rotational ARFORGEN-based and one sustained readiness–based), though additional readiness models could be added. Throughout this documentation and the tool itself, periods are referred to as months, because we believe that months are the correct level of analysis for the types of problems that MPAFF hopes to address. Additionally, the existing implementation of ARFORGEN and steady-state readiness models is based on monthly periods. However, the tool is generally agnostic to period length, and a more granular approach (days) or less granular

1 Steady-state demands correspond to activities commonly included in Phase 0/1 of the six-phase Joint Operational Construct. These phases cover shaping and deterrence activities. For more on the six-phase Joint Operational Construct see, for example, U.S. Joint Chiefs of Staff, 2011.

2 Scenarios correspond to activities commonly included in Phases 2/3 and 4/5 of the Joint Operational Construct. Phase 2/3 includes surge operations with seize and dominate missions, while Phase 4/5 covers stability operations.

approach (quarters) could be used without making any adjustments outside of the demand inputs, unit rotation/readiness schedules, and readiness model rules.

Inputs

The MPAFF tool is controlled at the highest level from the *Inputs* worksheet. From this worksheet, users can specify many run parameters or access other worksheets that control these settings.

Supply Inputs

Supply inputs control the size of the force that can be used in fulfilling scenario demand. Supply consists of the types of units available (AC versus RC), the number of units available, and projected force growth.

Baseline Supply

From the *Inputs* worksheet, users can set baseline supply information for each unit type by clicking the "Supply inputs" button or navigating to the *Supply* worksheet. It is on the *Supply* worksheet that unit types and their names are set and filled throughout the rest of the tool. The tool is agnostic to the level of specificity with which units are defined, meaning that units can be as small or large as desired. For example, some units may be entered at the battalion or brigade level and others at the company level. The only restriction is that supply and demand must be specified at the same level for a specific unit type. Unit types are specified in the table in this worksheet, with each new unit type being entered on a new line. For each unit type, the following information must be specified:

- unit type name: a text name for this unit type, to be used throughout the tool
- RC usage indicator: Enter "Yes" or "No," indicating whether RC usage is potentially allowed for this unit type. Note that if RC usage is disallowed either globally or for a particular scenario, RC cannot be used in these cases regardless of the value entered here.
- AC quantity: number of AC units of this type in the force
- RC quantity: number of RC units of this type in the force
- readiness models: Parameters specific to a given readiness model control policies governing expected readiness behavior. A drop-down menu selects the readiness model for each unit type.
  - Rotational ARFORGEN readiness models selected by choosing "Rotational" from the dropdown menu include the following parameters:
    - AC BOG:Dwell ratios:
      - Steady-state BOG:Dwell ratio (entered under Phase 0/1 inputs) is used prior to the start of the first scenario demand and in later periods when no

scenario is under way. Scenario demands and surge status are explained further in the introduction and the scenario demand section.
        - Surge BOG:Dwell ratio (entered under Phase 2/3 inputs) is used if any ongoing wartime scenario is currently in surge state. As explained above, scenarios consist of surge and sustainment components.
        - Sustainment BOG:Dwell ratio (entered under Phase 4/5) is used if there is an ongoing scenario but no surge is happening during this period.
        - Surge BOG:Dwell ratio (entered under Phase 2/3 inputs) is used if any ongoing wartime scenario is currently in surge state. As explained above, scenarios consist of surge and sustainment components.
        - Sustainment BOG:Dwell ratio (entered under Phase 4/5) is used if there is an ongoing scenario but no surge is happening during this period.
    - RC BOG:Dwell ratios:
        - Steady-state BOG:Dwell ratio (entered under Phase 0/1 inputs) is used prior to the start of the first surge and in later periods when no scenario is under way. Surges and scenarios are explained further in the introduction and the scenario demand section.
        - Surge BOG:Dwell ratio (entered under Phase 2/3 inputs) is used if there is any surge happening during this period in any scenario.
        - Sustainment BOG:Dwell ratio (entered under Phase 4/5) is used if there is a scenario but no surge happening during this period.
        - The RC delay parameter allows the user to specify how long it takes for RC units to become available at the start of a conflict. No RC units of a particular type may deploy to a contingency for the first *N* months at the start of the first war following a time of peace (no ongoing scenario). This reflects the need for RC mobilization and training and corresponding delay in arrival. This delay could be long for BCTs and other large units and very short for certain enablers.
        - Note that for RC units, the ARFORGEN cycle automatically includes a three-month mobilization period at the start of every available period. Therefore, an RC unit cannot deploy until three months after it reaches C1 (or C2, if allowed to deploy as C2) status.
- Sustained readiness models contain the following parameters:
    - An AC-only sustained readiness model can be applied by selecting the "Sustained AC/Rotational RC" option from the dropdown menu.
        - For AC units, the total inventory can be split into a set of tiers with some percentage of the force kept at C1, some percentage kept at C2, and some of the force designated as never being ready. The unusable units may represent training units or units undergoing equipment maintenance, which will be filled by individual rotation. A BOG:Dwell input is available for

sustained readiness, dictating how long a unit takes to reset upon deployment. Units reset only after a deployment, and C2 units begin moving toward C1 readiness when the system is in a war state.
    - RC units continue to use an ARFORGEN readiness model.
  - an AC and RC sustained readiness model
    - AC units use the same sustained readiness model as described previously.
    - For RC units, the total inventory can be split into usable and unusable units. The unusable units may represent training units or units undergoing equipment maintenance, which will be filled by individual rotation. The mobilization rate defines the rate at which RC units can complete necessary training to participate in a contingency situation. In this model, RC units are not used during peacetime but become available at the specified monthly rate throughout the course of a conflict, until usable RC is exhausted. The mobilization rate represents a constraint, such as the need to complete a CTC rotation.[3] A rate of less than one unit per month implies that units become available only every few months. An additional input dictates the number of periods required to reset a unit after deployment. Note that the three-month post-mobilization training period is not added in addition to the number specified here.
- RAND continues to develop additional and future readiness model options.

To give users full control over the ARFORGEN and sustained readiness calculations, the *Supply* worksheet includes two additional sets of inputs that are not unit type specific. The *ARFORGEN basis* parameters allow the user to set the base number of months against which the BOG:Dwell ratios are assessed. For example, a 1:3 ratio with a 12-month basis yields a 12:36 scheme, while a 1:3 ratio with a nine-month basis yields a 9:27 scheme. This basis can be managed separately during peacetime and war and for AC and RC. The second set of parameters controls *deployment length* and sets the basis length of deployment for AC and RC units separately if they deploy during their available period.

Force Growth

The user can specify force growth throughout the tool run by clicking the "AC force growth" or "RC force growth" button or navigating to the *AC force growth* or *RC force growth* worksheets. Once the user has specified unit types on the *Supply* worksheet, both of these worksheets will list the available unit types in column B. Specifying any nonzero number *N* to the right of a particular unit name indicates that *N* additional units of that type are added to the inventory during the period indicated in row 4.

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3 A CTC rotation provides Joint and combined arms collective training at the brigade level.

These new units enter at the lowest readiness level. In sustained readiness mode, the new units are added to the most ready (C1) assigned readiness tier.

Demand Inputs

The user can specify demands for the steady state and for up to 12 individual scenario demands, which consist of surge and sustainment components. Note that all demands should be entered explicitly, meaning that the number of units indicated in a given period is the total number of units required during that period. This is in contrast to indicating only new units in each period, as is sometimes seen in TPFDL data.

Steady-State Demand Inputs

To modify steady-state inputs, users can click on the "Ph 0/1 inputs" button or navigate to the *Ph 01* worksheet. Like supply data, steady-state demands are organized by unit type. Unit type names will be prefilled based on information entered in the *Supply* worksheet. For each unit type, steady-state demands can then be specified by COCOM and by their necessity during wartime. Steady-state demands can be specified for each COCOM:

- USAFRICOM
- USCENTCOM
- USEUCOM
- USNORTHCOM
- USPACOM
- USSOUTHCOM

For each of these COCOMs, the user must supply four demand quantities:

- total rotational demand: This indicates the total number of rotational units of the given unit type demanded within that COCOM during peacetime.
- war capable rotational: This indicates how many of the rotational units of the given unit type listed under "rotational demand" may be used to fulfill war demands in this COCOM when a scenario is ongoing *in this COCOM*. Note that the "rotational war capable'" entry may not exceed the "rotational demand" entry. If there is no scenario demand for the war capable units, they continue to be used to fulfill the steady-state mission.
- rotational war optional: This indicates how many of the total number of rotational units of the given unit type listed under "rotational demand" become optional when a scenario is ongoing *outside of this COCOM, and there is no scenario ongoing within this COCOM*. Note that the "rotational war optional" entry may not exceed the "rotational demand" entry. If sufficient supply is available, all demand (including "rotational war optional" demand) will be filled. Note that

if "optional" demand is missed (not enough units are available to fill it), this is represented in the outputs as a reduction in total demand, not as missed demand.

- home-stationed demand: This indicates how many nonrotational forward-stationed units are demanded in this COCOM. The tool treats home-stationed units as though they are always available (ready) during peacetime. Therefore, these units are always able to fulfill the demand for home-stationed units to which they are originally assigned. Home-stationed units deploy to a war in their COCOM when it starts and must reset after their deployment, during which time they do not count toward fulfilling war demand. The rate of reset is based on the same readiness cycle used by other units of their type in the current run. Other units must replace home-stationed units while they reset. Home-stationed units continue to rotate through the same readiness cycle as other units of the same type as long as a war continues.

As an example illustrating these rules of steady-state demand reduction in times of war, we might specify steady-state demand for unit type A in USAFRICOM as shown in Table A.1.

During peacetime, the steady-state rotational demand to USAFRICOM would be four units of type A. Wartime demand for unit type A is dependent on where the conflict is occurring and whether or not sufficient units of type A are available, as shown in Table A.2.

Scenario Demand Inputs

Any demands above and beyond the baseline steady state are captured in scenarios. To edit demands for a particular scenario, navigate to the appropriate scenario workbook (named, e.g., *Scenario 1*).

Within each scenario worksheet, users can specify specific information about the scenario:

- Scenario description: Text description of the scenario, for user readability.
- Scenario COCOM: Select one of the six COCOMS in which this scenario takes place. COCOM selection affects which steady-state units can be reassigned to this scenario or become optional during a surge.
- Surge start: Month of the scenario in which surge starts. Surge timing affects which readiness rules will be used. During any simulation period in which a surge is ongoing, surge readiness parameters (such as ARFORGEN rotation rates) will

Table A.1
Example War Demands in USAFRICOM (Rotational)

Rotational Demand	Rotational War-Capable Demand	Rotational War-Optional Demand
4	2	1

Table A.2
Scenario Example War Demands in USAFRICOM

War Scenario Characteristics	USAFRICOM Steady-State Demand for "Unit Type A"
Scenario(s) within USAFRICOM requiring *N* units of type A during this period	4–(min(N,2)) units of type A are required for steady state in USAFRICOM. So long as the scenario(s) occurring in USAFRICOM this period require at least 2 units of type A, the 2 war-capable units from the steady-state demand are reassigned to the scenario mission.
Scenario(s) outside of USAFRICOM but no ongoing scenario within USAFRICOM	4–1=3 units of type A are required for steady state in USAFRICOM this period. The 1 war-optional unit of type A is no longer required, signaling an ability to disengage from steady-state operations in times of conflict. Note that if sufficient ready units of type A are available, 4 units of type A will be deployed against both the required and optional USAFRICOM steady-state demands.

be used. Whenever a scenario is ongoing but no surge is ongoing, regular wartime readiness parameters will be used. Month 1 is the first month of the scenario.
- Surge end: Month of the scenario in which surge ends.

The remainder of scenario parameters is specified for each unit type individually. Unit names are again prepopulated from the list on the *Supply* worksheet. For each unit type, the user must specify

- AC usage indicator: Enter "Yes" or "No," indicating whether AC usage is allowed for this unit type in this scenario.
- RC usage indicator: Enter "Yes" or "No," indicating whether RC usage is allowed for this unit type in this scenario. Note that if RC usage is disallowed globally for this unit type regardless of scenario, RC cannot be used regardless of the value entered here.
- AC C2 usage indicator: Enter "Yes" or "No," indicating whether AC units may be deployed at the C2 readiness level. Note that if AC C2 usage is disallowed globally, then these units cannot be used regardless of the value entered here. If AC is disallowed (globally or within the scenario), then AC C2 units cannot be used.
- RC C2 usage indicator: Enter "Yes" or "No," indicating whether RC units may be deployed at the C2 readiness level. Note that if RC C2 usage is disallowed globally, then these units cannot be used regardless of the value entered here. If RC is disallowed (globally, for this unit type, or within the scenario), then RC C2 units cannot be used.
- Demand per period: Enter the number of units of the given unit type demanded for this scenario in each period.

Other Simulation Run Parameters

Several additional run-time inputs can be specified directly on the *Inputs* worksheet.

Scenario Selection and Timing

The dropdown box on the *Inputs* worksheet allows the user to enter all scenarios that should be included in the run. The interface is currently set up to handle up to 12 scenarios. Select the scenario name from the dropdown and indicate a month in which this scenario should start. Scenarios do not need to be entered in chronological order. However, the tool will attempt to fill scenario demands in the order in which they are specified in this list in each period. Multiple scenarios may start in the same month. Scenarios may overlap. Note that the total run length is defined by a separate input at the bottom of this worksheet. Ensure that total simulation length is long enough to allow all scenarios to finish, or the tool will produce an error. Scenarios may not start in period 1. It is advisable to allow at least 30 periods of peacetime operations prior to the start of a conflict for steady-state and force generation processes to stabilize.

Prioritization

The user may globally disallow the use of specific readiness levels of units on the *Inputs* worksheet, namely AC C2 and RC C2 units. If these units are disallowed here, they will be globally disabled regardless of settings in individual scenarios or for individual unit types. In this section, the user must also specify a priority ordering for the allowed readiness levels. These are AC C1, AC C2, RC C1, and RC C2. Limitations on possible prioritizations exist; a C2 unit may not be used before a C1 unit from the same component, and RC is generally used after AC (unless AC use is specifically prohibited for that unit type/scenario). In the run, higher-priority units will be used to fulfill demand first, whenever available.

Extensions

This section allows the user to specify the lengths of deployment extensions. The length of deployments may be extended from the default length specified in the *Supply* worksheet in both steady state and times of war (when a scenario is ongoing). The tool is in steady state whenever no scenario is ongoing during that period. While each readiness model's settings will include a standard deployment length, the length of deployments may be extended from the default length both in steady state and while a scenario is ongoing. Extensions are added to the default deployment, and wartime (scenario) extensions are added to steady-state extensions during periods when any scenario is ongoing if both are nonzero values. Once a particular unit is extended, it stays extended even if all ongoing scenarios end during its deployment. The exception is a special setting that ends all extensions when war ends. If demand winds down quickly at the end of a scenario, units will end their deployments early if they are no longer needed, because units for which there is no demand will be sent to reset. At the end of a conflict, as demand draws down, the longest-deployed units of a given unit type are those that will be sent to reset first.

Run Length

The tool is run for the number of periods (months) specified. It is advisable to allow at least 30 periods of peacetime operations prior to the start of a conflict for steady-state and force generation processes to stabilize. The total number of periods run should be sufficient to allow all scenarios to complete, given their start times.

Running the Tool

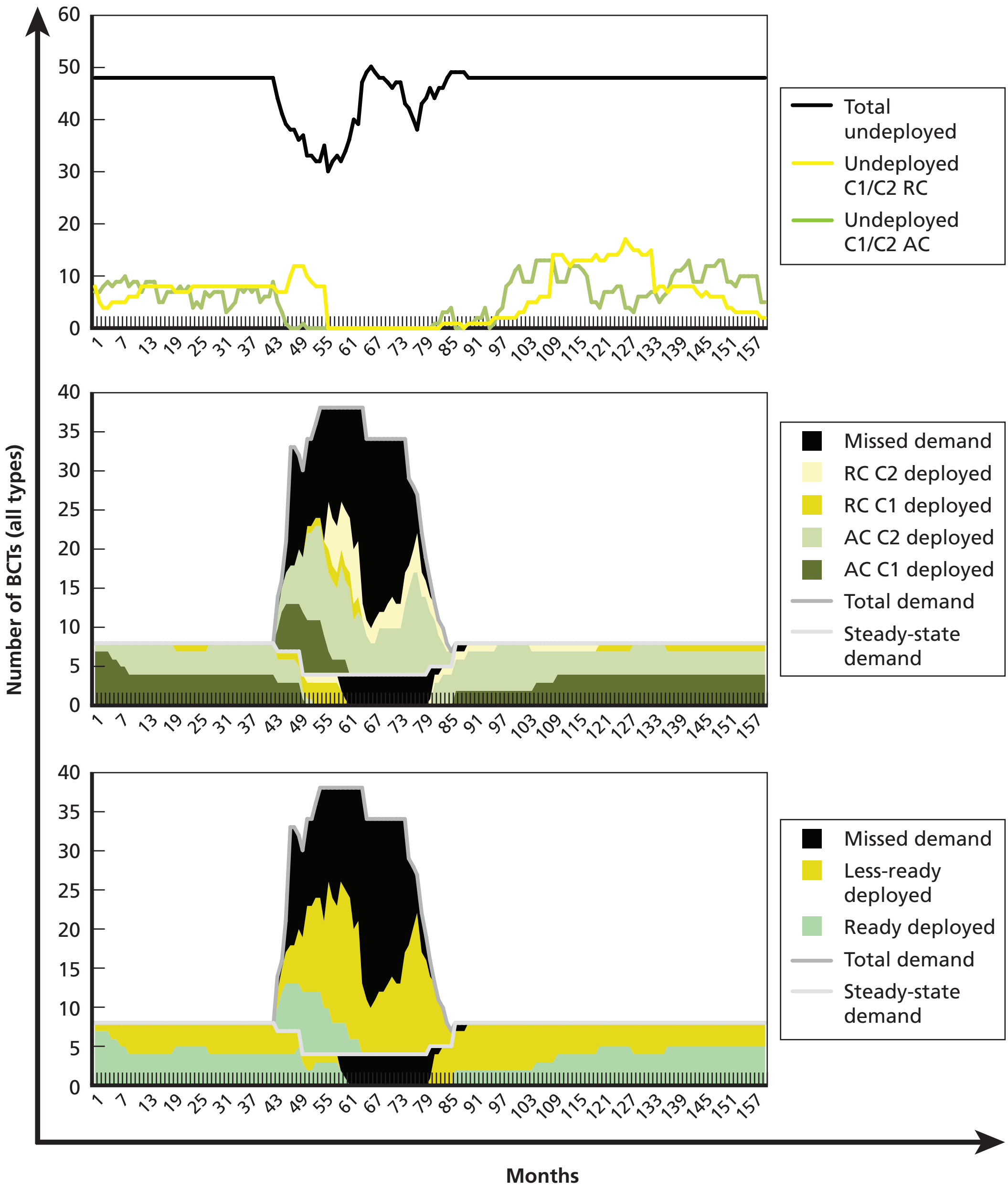
In order to run the tool, specify all inputs described in the inputs section of this document. Once all inputs reflect the desired run, set the number of periods for which the tool should be run and hit the "Run model" button at the bottom of the *Inputs* worksheet. The tool will run and automatically open the *Outputs* worksheet. On this sheet, the user can select which unit types should be included in output graphs. If multiple unit types are selected, the plots will present aggregate results obtained by adding results from individual unit types.

Generating Outputs

Outputs will appear on the *Outputs* worksheet once the tool is run (by clicking on the "Run model" button on the *Inputs* worksheet). On this sheet, the user can select which unit types should be included in the output graphs and table. If multiple unit types are selected, the plots will present aggregate results obtained by adding results from individual unit types. Note that results are reported as numbers of units, so aggregate results for unit types of very different sizes may become difficult to interpret. Three automatic output plots are created for each run. Samples of these plots are shown in Figure A.1. The top panel of Figure A.1 plots the number of undeployed units over time, giving some idea of the percentage of the total force structure for a unit type or set of unit types being employed. The second panel shows met and missed demand, with met demand broken out by component and readiness level of the deploying units. Green shading indicates demand met by AC units (darker green for C1 units, lighter green for C2 units), while yellow indicates demand met by RC units (darker yellow for C1 units, lighter yellow for C2 units). Black indicates missed demand. The third panel of Figure A.1 also plots met and missed demand, distinguishing only between fully ready units (green) and less-ready units (yellow).

Input data for the plots are presented numerically underneath the plotting windows and can be used to create ad hoc plots that highlight specific areas of interest. A

Figure A.1
Illustrative Raw MPAFF Tool Outputs



NOTE: For additional figure explanations, see note under Figure 3.1, as well as description in this section.

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great level of detail on readiness over time is available in this table. The components of the output table are

- total demand: total demand across steady state and all scenarios in this period, in number of units
- SS demand: steady-state demand in this period, in number of units
- AC war deploy: number of C1 AC units deployed to a scenario
- AC war deploy C2: number of C2 AC units deployed to a scenario
- AC SS deploy: number of C1 AC units deployed to the steady state
- AC SS deploy C2: number of C2 AC units deployed to a scenario
- RC war deploy: number of C1 RC units deployed to a scenario
- RC war deploy C2: number of C2 RC units deployed to a scenario
- RC SS deploy: number of C1 RC units deployed to the steady state
- RC SS deploy C2: number of C2 RC units deployed to a scenario
- missed scenario demand: number of demanded units across ongoing scenarios in this period met by neither AC nor RC
- missed SS req. demand: number of mandatory (nonoptional) demanded units for steady state in this period met by neither AC nor RC
- undeployed C1/C2 AC: number of undeployed AC units in C1 or C2 readiness state
- undeployed C1/C2 RC: number of undeployed RC units in C1 or C2 readiness state
- undeployed C1/2/3/4/5 AC: five separate entries indicating the number of undeployed AC units in each of the C1/2/3/4/5 readiness states
- undeployed C1/2/3/4/5 RC: five separate entries indicating the number of undeployed RC units in each of the C1/2/3/4/5 readiness states
- surge status: indicator for whether a scenario is currently ongoing in any COCOM in this period. Zero indicates no current scenarios, 1 indicates the presence of scenarios but lack of a current surge, and 2 indicates the presence of a current surge operation.
- undeployed AC: total number of undeployed AC units
- undeployed RC: total number of undeployed RC units
- total undeployed units: total number of undeployed AC and RC units
- SS ready deploy: total number of units deployed to steady-state operations that deployed at C1 status
- SS less-ready deploy: total number of units deployed to steady-state operations that deployed at C2 status
- war ready deploy: total number of units deployed to a scenario that deployed at C1 status
- war less-ready deploy: total number of units deployed to a scenario that deployed at C2 status.

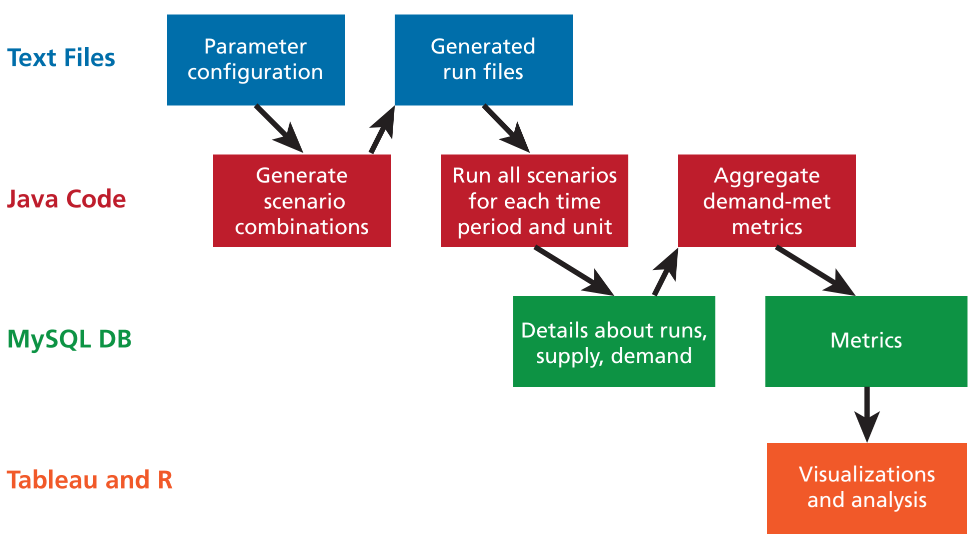
APPENDIX B

Supplemental User Guide for MPAFF-J Tool

This user guide expands on the conceptual tool description found in Chapter Five to provide guidance for running the MPAFF-J tool. MPAFF-J is not designed for interactive employment by end-users but rather for command-line analysis performed by experienced analysts. The descriptions here assume a fair amount of technical sophistication by the reader. The documentation is focused on documenting the contents of "configuration scripts" but assume the audience knows how to create and/or edit such scripts. Users interested in further details should contact Rebecca Balebako (balebako@rand.org).

Figure B.1 shows that a number of pieces are involved in the MPAFF-J setup. This guide is written for a user interested in configuring and running the tool to examine a set of scenario outputs. This work largely involves examining and tweaking the configuration scripts and pulling the aggregated information from the database into a

Figure B.1
Steps and Tools to Configure and Run the MPAFF-J Tool



RAND *RR1954-B.1*

visualization tool. We describe the process of running the tool and provide details on the configuration files and the database.

Simulation Steps

1. Modify Parameter Configuration Scripts

The MPAFF-J tool is largely configured by collection of text configuration files. The code repository includes sample configuration scripts in the *Input* directory. The configuration scripts contain supply and demand signals and other configuration inputs to run the tool. Each configuration file designates the parameters for that run. The following configuration files are included in the base directory:

- Base.cfg : Options such as length of each simulation, location names, unit deployment prioritization, and the units to include in the simulation.
- Scenarios.cfg: Scenarios are grouped by location and set, providing the ability to configure, for example, a long PACOM scenario and a short PACOM scenario.
- For each scenario set, we define further configuration files with details of that scenario and the start times. The scenario detail files will include the scenario length, start time, location, and demand signal.
- Steady_states.cfg: Maps each steady-state name with the supply file in csv format
- Supplies.cfg: Maps each supply size name with the supply file in csv format.
- Active_readiness_models.cfg: This could include ARFORGEN or sustained readiness models, or other models as they are developed. Maps the AC readiness model to the readiness detailed config and supply file. The detailed config includes which Java class readiness model to use.
- Reserve_readiness_models.cfg: Maps the RC readiness model to the readiness detailed config and supply file. The detailed config includes which Java class readiness model to use. This is only used in the ARFORGEN model.

The text configuration files generally are of the format of [parameter name]=[parameter value]. However, the supply and demand configuration files are tabular and in comma-separated value format. This allows for each unit type's configuration values on a separate row.

If the parameter value in the cfg file has more than one option, the MPAFF-J can be configured to generate a combination of all possible values and run each combination as a simulation.

To run the MPAFF-J tool itself, a levers directory needs to be created; this directory will contain a combinatorial expansion of all the parameters we intend to run against in our RDM tool.

2. Confirm That Database Exists

A MySQL database with the appropriate schema must exist. The schema is found in the code source documentation. This is where all the output information about each scenario run is stored.

3. Create Levers Files

The Java code will create a file for each simulation requested. It does so by reading in the configuration files above and calculating the complete set of combinations possible. A separate text file will be written to the levers directory for each simulation to be run.

The Java code to create the levers (or simulation) files is

java unitreadinessdod.UnitReadinessConfigure --make-levers.

It is important to note that if hundreds of thousands of files are created, most graphical operating systems will navigate the directory very slowly. Therefore, we provide the Java code to delete these files after the simulation has been run.

java unitreadinessdod.UnitReadinessConfigure --clean

3. Initialize the Simulation by Inputting All Run Configurations

Run the Java code, supplying the appropriate information about the input files configured in step 1 and the database information in step 2. An example start to the simulation from the command line would be

java unitreadinessdod.UnitReadiness
--input=input/
--output=output/
--db=jdbc:mysql://localhost/unitreadiness
--user=dbname
--passwd=dbpassword
--levers=input/levers

The *Driver* class owns and runs the overall *SimulationRun* class that encapsulates the entire simulation. The *SimulationRun* owns the individual *UnitSimulationRun*s for each unit type.

Each *UnitSimulationRun* is configured via the configuration file input in the above step. Factory classes are responsible for reading in the configuration files and instantiating the corresponding classes. Once each *UnitSimulationRun* has been initialized and configured, it writes its configuration parameters to the database via a database connector class (possibly a singleton owned by the *SimulationRun* or *Driver*). A unique simulation ID is created for logging. The data are also stored and accessed in memory in the form of lists and hashmaps; the database is used only for logging and is not accessed during the simulation.

4. Java Code Will Execute Each of the Runs

The MPAFF-J tool does this step automatically. We provide the logic of the code for explanatory purposes in this step.

Each *UnitSimulationRun* iterates through every period, reading its demands for the period, deploying units in the supply to meet the demand, and advancing the units through its readiness cycle. During each period iteration, *UnitSimulationRun* collects important metrics (e.g., units deployed, units demanded, missed demand) about the period and saves them to a database.

1. Instantiate *UnitSimulationRun*s for each unit type.
2. Initialize units.
   a. Distribute units evenly across the readiness levels as defined by the unit's readiness model:
      - For ARFORGEN, units are distributed across readiness levels C1, C2, C3, C4, and C5 using the BOG:Dwell ratio.
      - For Sustained Readiness, units are distributed by their tiered C1, C2, and unusable percentages.

   b. Deploy units to meet initial demand (currently only steady state).
   c. Evenly space deployed units across deployment duration.
   d. Evenly space remaining C1 undeployed troops to make up for deployed units.

3. Iterate through each unit type, step through period.
   a. Deploy most ready units to meet scenario demand.
   b. Deploy units that have already met steady-state demand in the same COCOM as the war, then
      - Deploy units that are furthest along in ready state.
        i. Deploy most ready units to meet steady state demand.
      - Undeploy units in scenarios whose quantities exceed demand.
        i. Undeploy units with the longest deployment length.
        ii. Undeploy units in steady state whose quantities exceed demand.
      - Save unit quantities for deployment, demand, and current readiness levels.

   c. Advance units by one period.
   d. Advance units' readiness level if needed.
   e. Send home units that are past their deployment length.

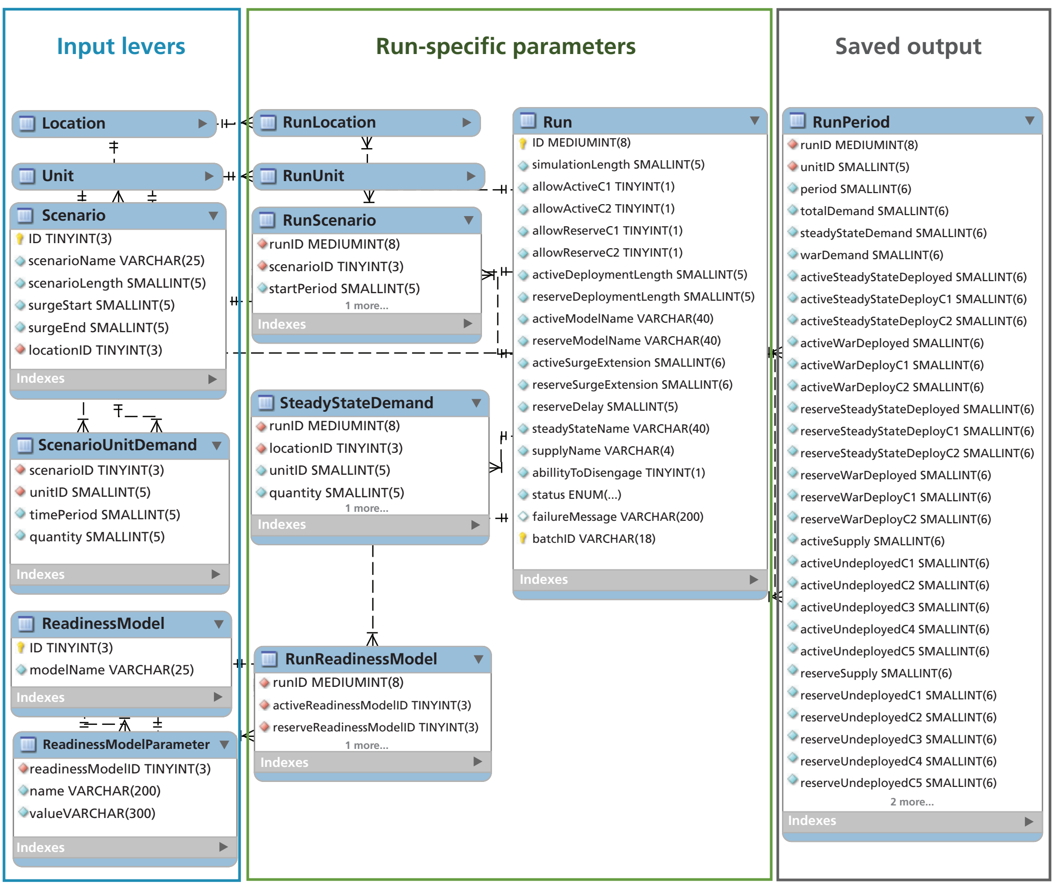
4. Repeat step 3 until simulation length is reached.

5. Output quantities for deployment, demand, and unit readiness levels at each period. *UnitSimulationRun* writes its run period metrics to the database via the database connector.
6. Close *SimulationRun*, clean up memory.

5. Aggregate Results Across Runs for Analysis

There are a number of options for exploring the results from the detailed simulation runs. After running the simulations, the saved output portion of the database may contain several gigabytes of data. This contains the details of each simulation met demand for each unit at each period. One may link to each simulation's configuration details by using the parameters tables described in "input levers" or the tables in the "run specific parameters" sections. For details on each period in each run, data can be analyzed in or exported from the MySQL database. The MySQL schema is shown in Figure B.2.

Figure B.2
The MPAFF-J SQL Database Schema Showing the Tables Read to and Written to by SimulationRun (additional tables for metric aggregation are not shown here)



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We have also developed a Java tool that aggregates across periods and units to output success or failure metrics for each simulation run.

A SQL script to export and aggregate the most relevant data is provided in the code repository.

6. Analyze the Data

The analyst can use Tableau, SQL, Excel or R-programming to aggregate information for each run and across levers and compute metrics. Chapter Five provides some examples of the type of analysis possible.

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